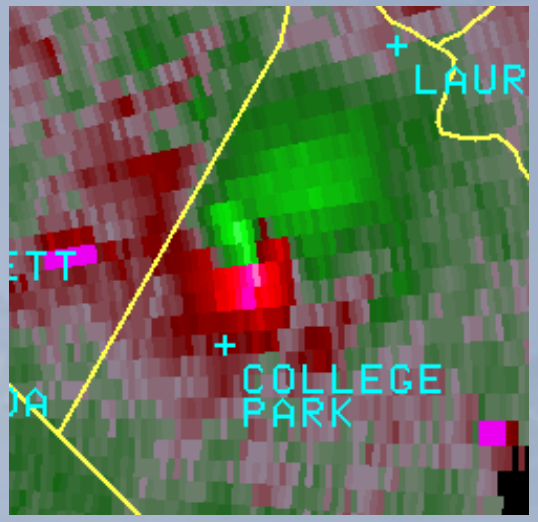
Severe Weather

National Weather Service
Baltimore/Washington Forecast Office

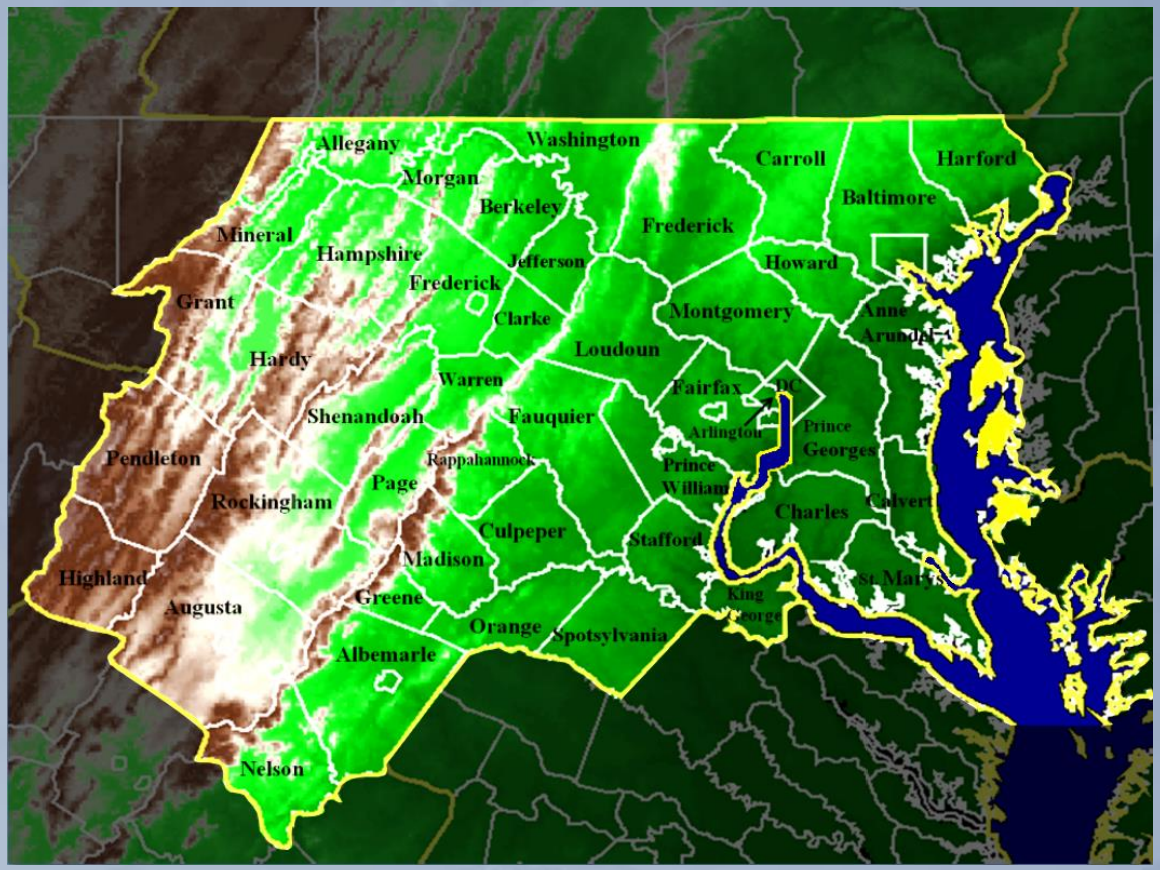
Today's Topics

- Severe Weather Storm Spotting Review
- Thunderstorms
- Severe Thunderstorms
- Radar Basics
- Advanced Interrogation Techniques
- Case Studies
- SPC Products



Area of Responsibility

- 13 MD Counties
- 8 WV Counties
- 22 VA Counties
  - 11 Independent Cities
- District of Columbia
- The City of Baltimore



…nearly 10 million people to look out for!

Why Do We Need Spotters?

Spotters report observed weather to the NWS during potentially severe weather events.

Remember our mission? The protection of lives and property. We can't do it alone. We need you, the local experts!

The information that you relay to us has the potential to save lives and property – helping us complete our mission.

Spotters Reports Should Contain the Who, What When & Where

- Who is making the report?
- What are you reporting?
- When did the event occur?
- Where is the location of the report?

Reporting Criteria

- **Tornado or Funnel**
- **Hail – Pea sized or larger**
- **Rotation within a storm**
- **Wind – 50 MPH or greater (sustained/gust and measured/estimated)**
- **Damage – Any weather related damage to trees or property. Give as many details as possible.**

Making a Report

- Include your **full name and Spotter Number**!

- Be as specific as possible about when the event occurred
  - We can go back and look at archived radar data

- What you are reporting (funnel, downed trees, etc)

How to Report Information

1. **Call NWS Baltimore/Washington if weather is imminent or occurring:**
   1.800.253.7091 OR 703.996.2201
2. **Email *delayed* weather reports to:**
   lwx-report@noaa.gov
3. **Contact local Emergency Management Officials**
4. **Relay your report through Amateur Radio when activated**

Thunderstorm Review

- Thunderstorm Ingredients
- Thunderstorm Life Cycle
- Types of Thunderstorms

Thunderstorm Ingredients

Moisture

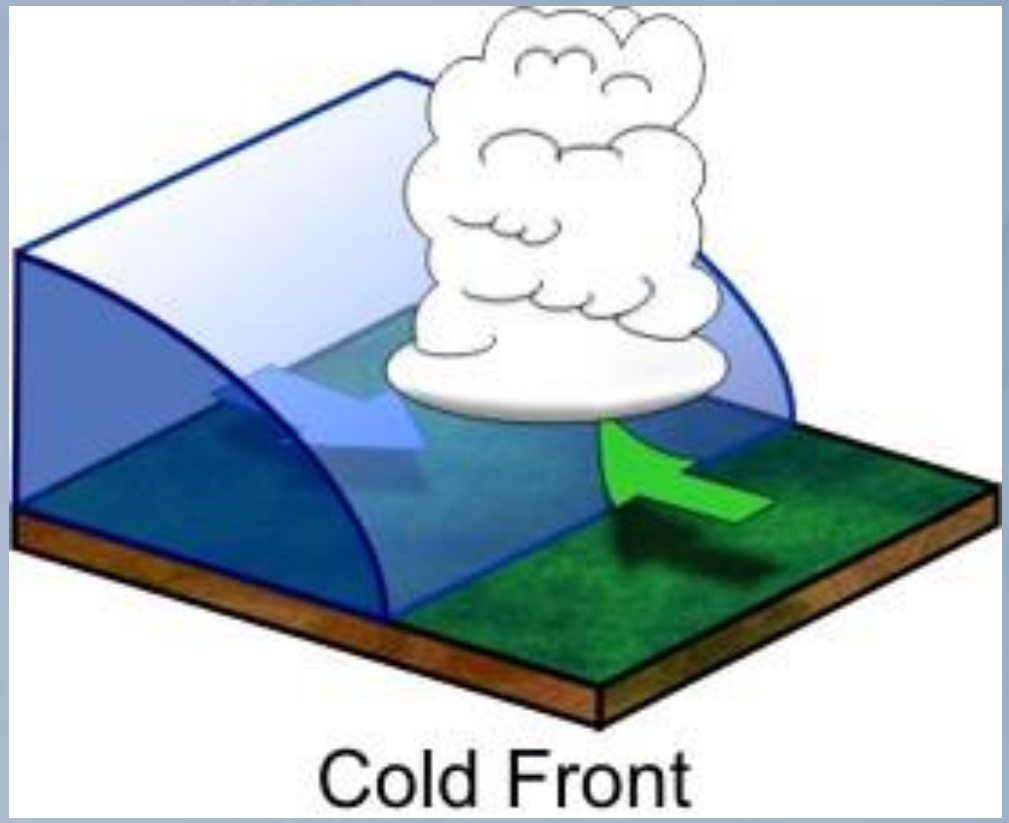
Our moisture sources are the Atlantic Ocean, Gulf of Mexico and the Chesapeake Bay.

Thunderstorm Ingredients

Lift

For lift, you need a mechanism or boundary for convergence. Cold fronts are a good source of lift.

When air is forced upward along a front, it cools/condenses and precipitation forms.



Convergence of wind along the cold front.

Thunderstorm Ingredients

Lift

Cold Front – cold air moving into warm

Warm Front – warm air moving into cold

Stationary Front – a stalled weather front

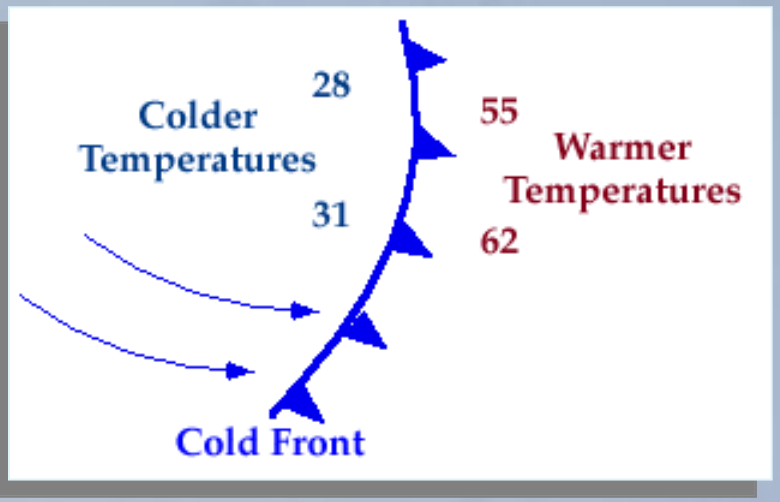
Bay Breeze – moist cool air moving inland

Orographic – hills/mountains

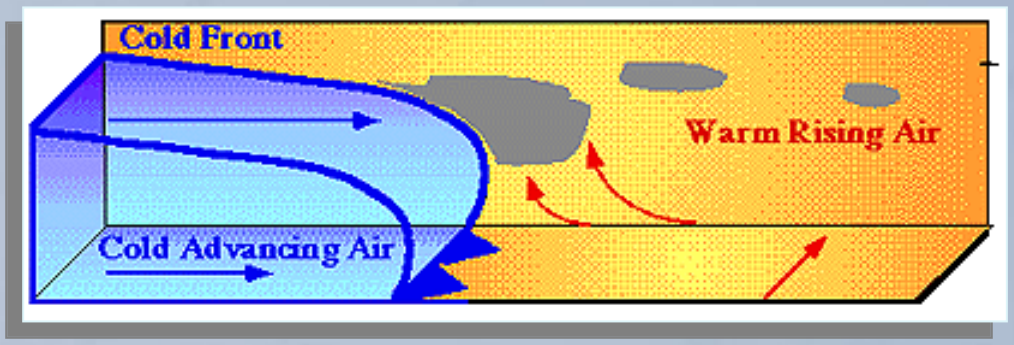
T-Storm Outflow – cold air blowing out of a thunderstorm

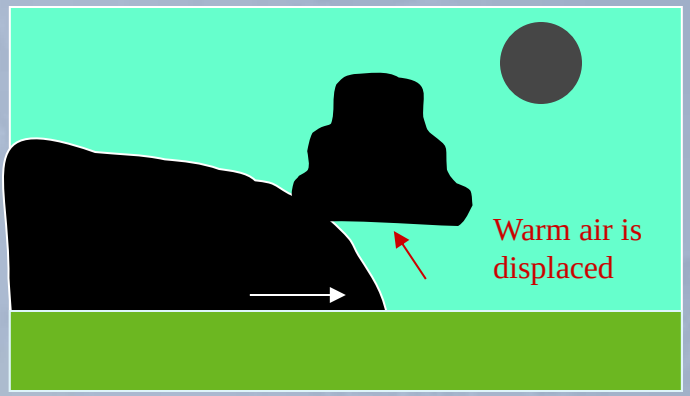
Thunderstorm Ingredients

Lift – Cold Front



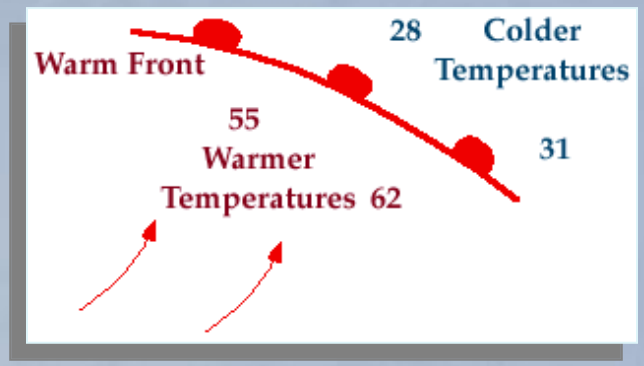
Colder air is denser than the warm air ahead of the front. The warmer air is forced to rise up. If the air is unstable, it will keep rising. Cold fronts often initiate lines of showers and thunderstorms.



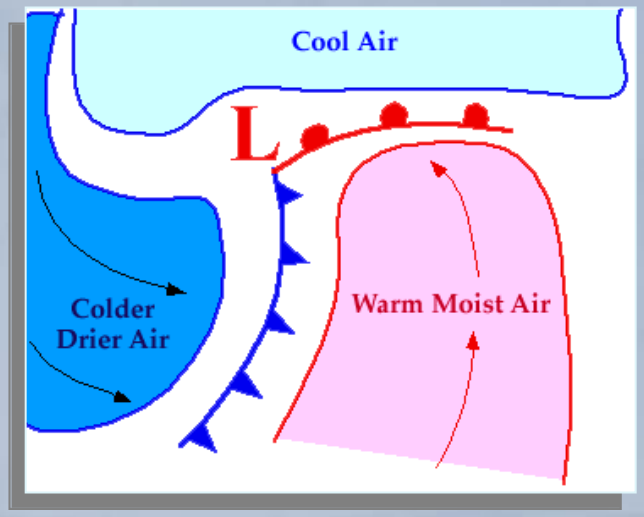


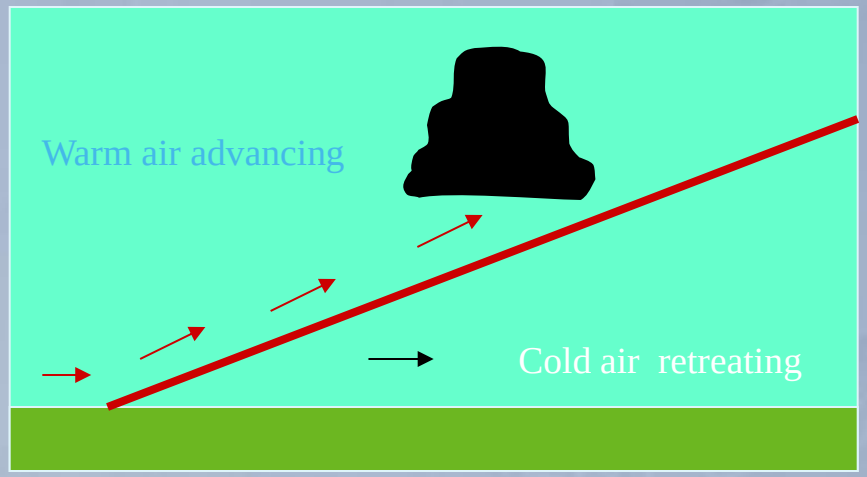
Thunderstorm Ingredients

Lift – Warm Front



Again, the colder air is denser than the warm air. As the warm air encounters the cold air, it is forced to rise up and over. If the air is unstable, showers and thunderstorms can form.





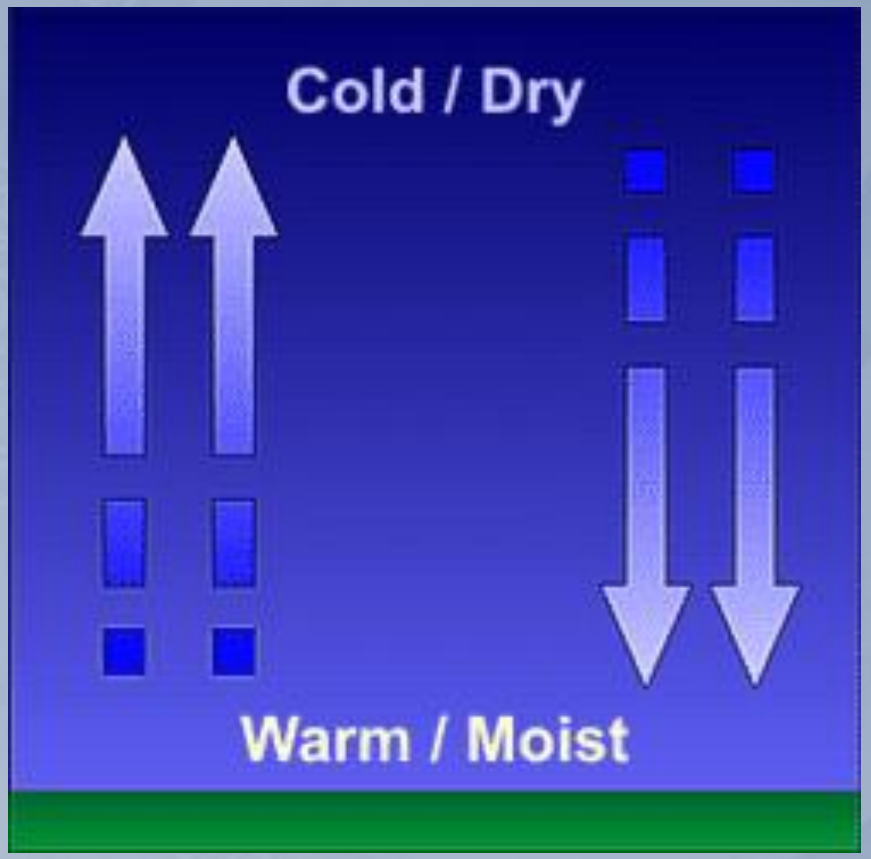
Thunderstorm Ingredients

Instability

An airmass is considered unstable if a parcel of air continues to rise when given a nudge upward (like a cold front).

In an unstable airmass, warm moist air is near the surface while cold dry air is aloft.

The more warm & moist the airmass is at the surface and the colder & drier the airmass is aloft…the more unstable the atmosphere is.



Thunderstorm Ingredients

Instability

Warm air **versus** **Cold air**

Same size air parcels

Warm air molecules are actively moving around limiting the number of molecules that an air parcel can hold. With less molecules per area, it is lighter.

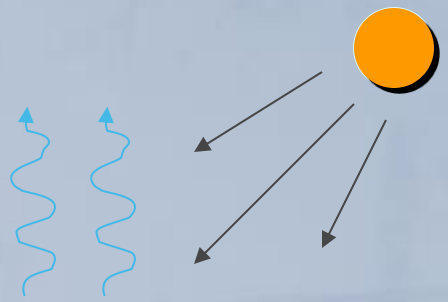
Cold air parcel packs in a lot of molecules. There is less movement. With more molecules per area, this air is heavier and denser.

Thunderstorm Ingredients

Instability

Warm air versus Cold air

- **Warm air is lighter than cold air and will rise if it is warmer than its surroundings.**
- **Cold air is heavier than warm air. If the air is colder than its surroundings, it will sink and stay close to the ground.**



Daytime heating is one way to warm up the lowest layer of the atmosphere.

Thunderstorm Ingredients

Instability

Dry air versus Moist air

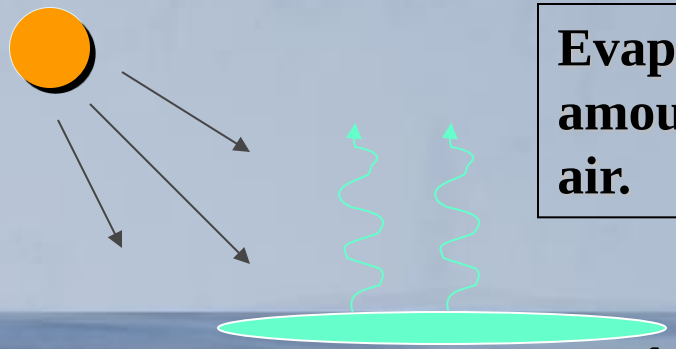
Molecule		Weight
Nitrogen (N_2)	78% of air	28
Oxygen (O_2)	21% of air	32
Water Vapor	H_2O	18

Thunderstorm Ingredients

Instability

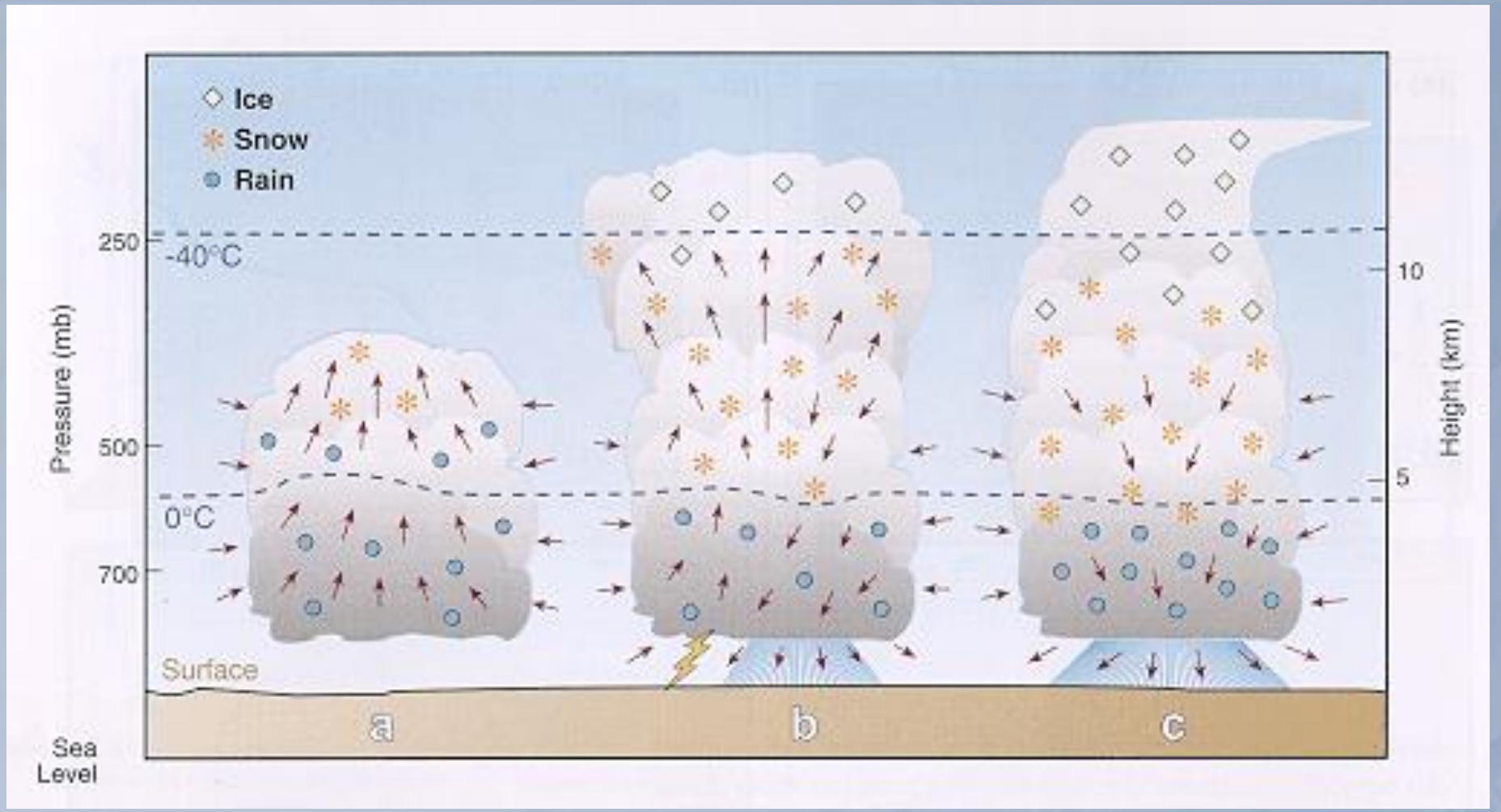
Dry air versus Moist air

- **Moist air is lighter than dry air. Therefore if a parcel of air is more moist than its surroundings, it will rise.**
- **Dry air is heavier. If air is drier than that around it, it will sink.**

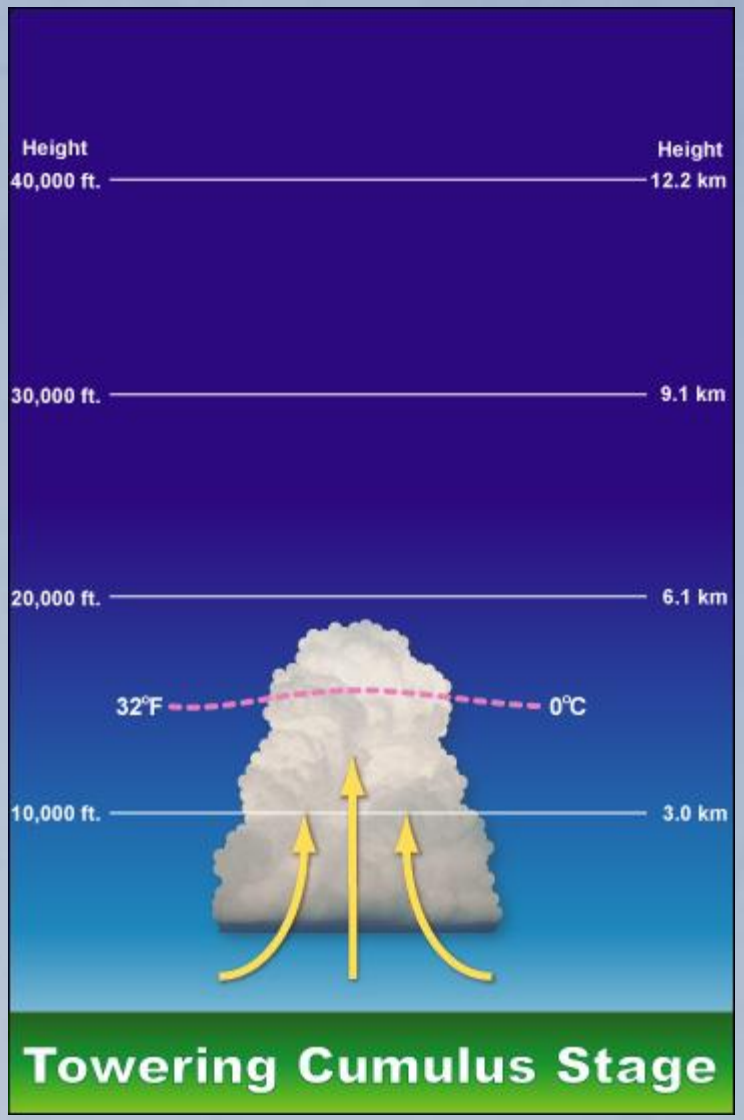


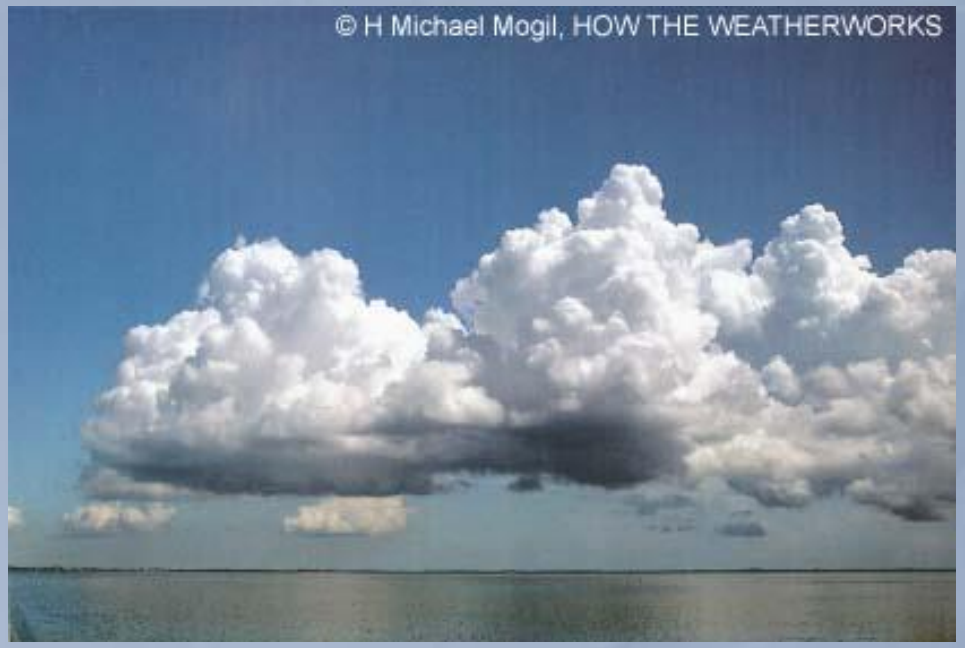
Evaporation is one way to increase the amount of water vapor and moisten the air.

The Thunderstorm Life Cycle



Cumulus Stage: Building Clouds

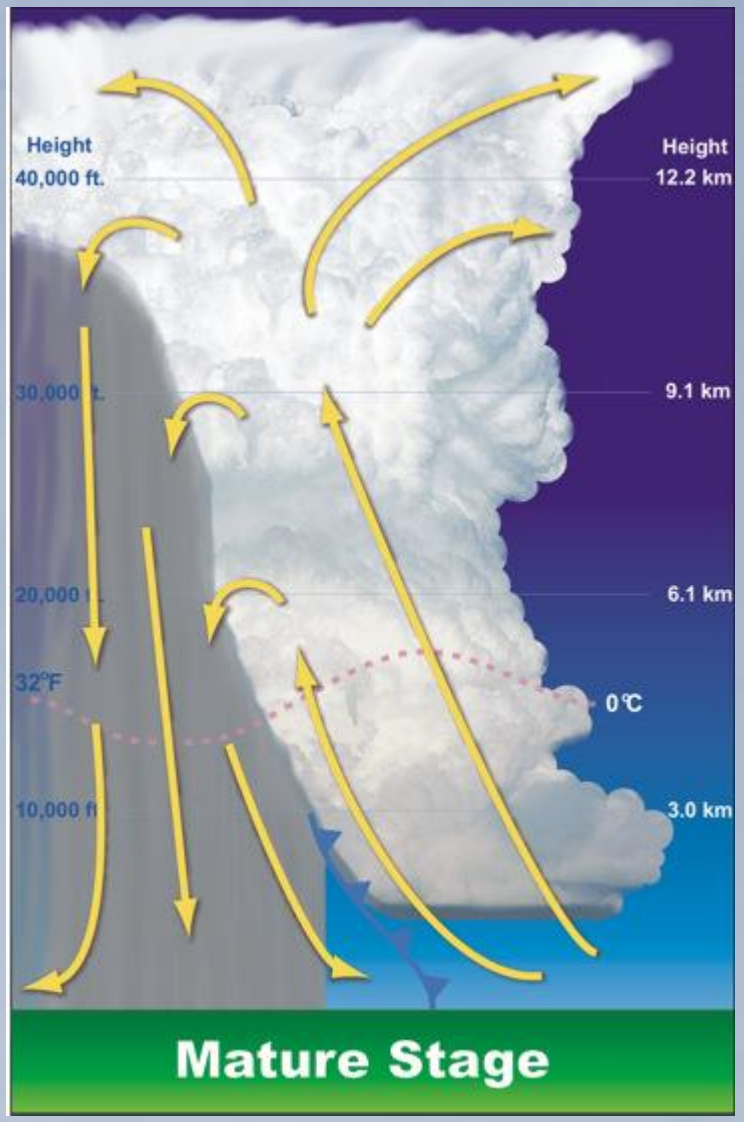




Updraft Dominant

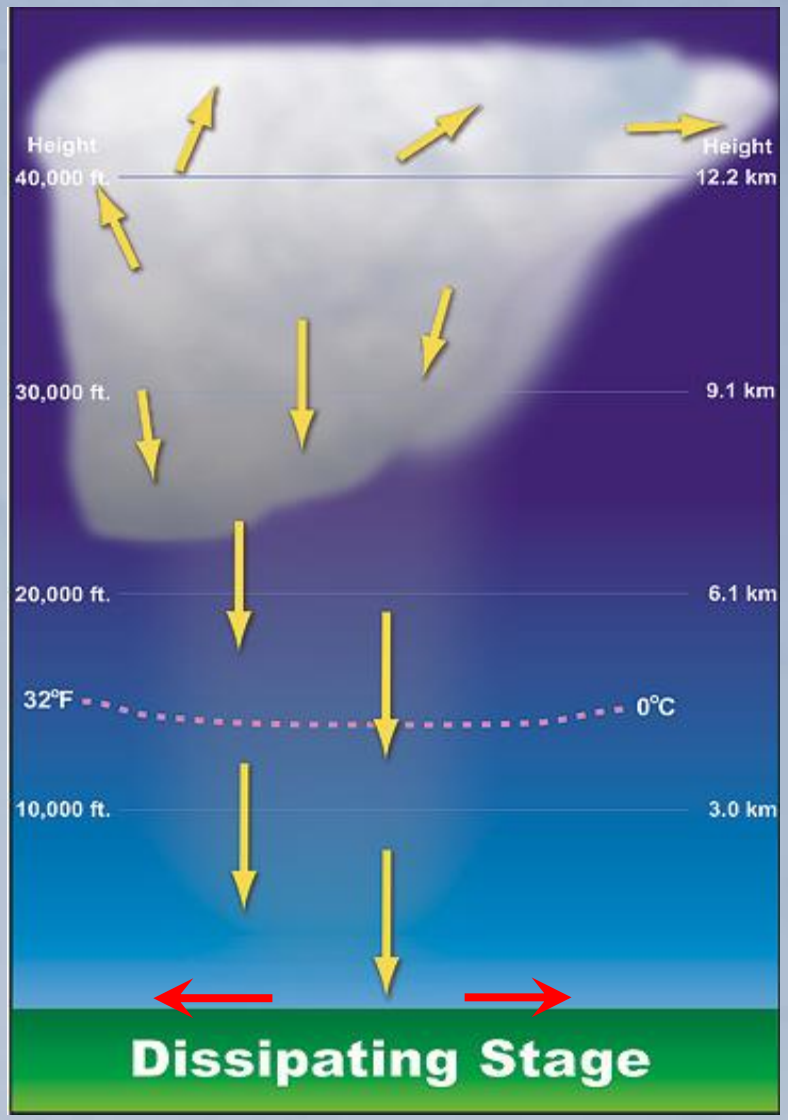
Warm air is rising, cooling and condensing to form clouds.

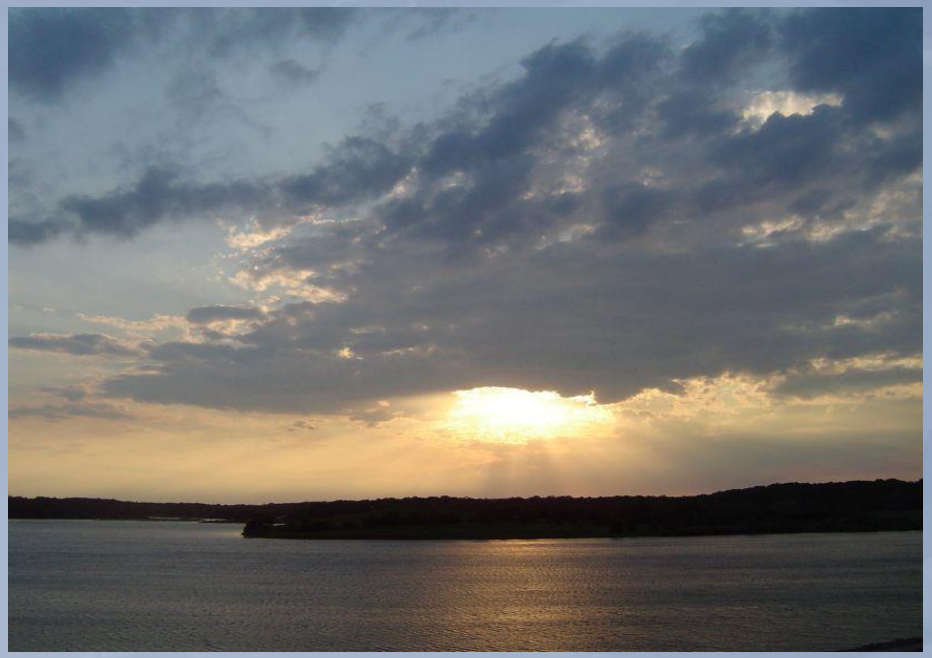
Mature Stage: Developed Thunderstorm



When the rain-cooled air impacts the surface and spreads out it creates a gust front. Sometimes winds can be very strong along the gust front.

Dissipating Stage: Weakening Thunderstorm





As the gust front moves away from the base of the storm, it cuts off the storms inflow and it begins to dissipate. The gust front may trigger new storms by convergence if the environment is moist and unstable.

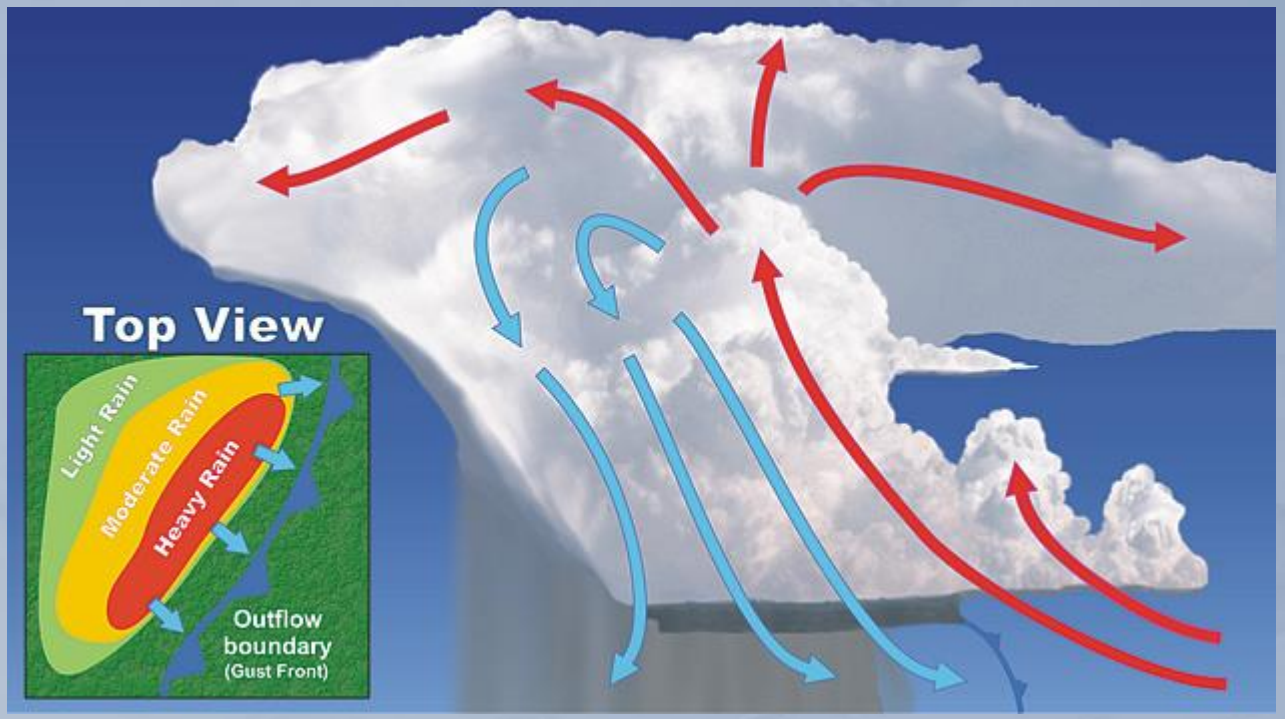
Types of Thunderstorms

Single Cell

- Generally Weak
- Short Lived
- Poorly Organized
- “Pulse Storms”
- Usually “Rainers”

Types of Thunderstorms

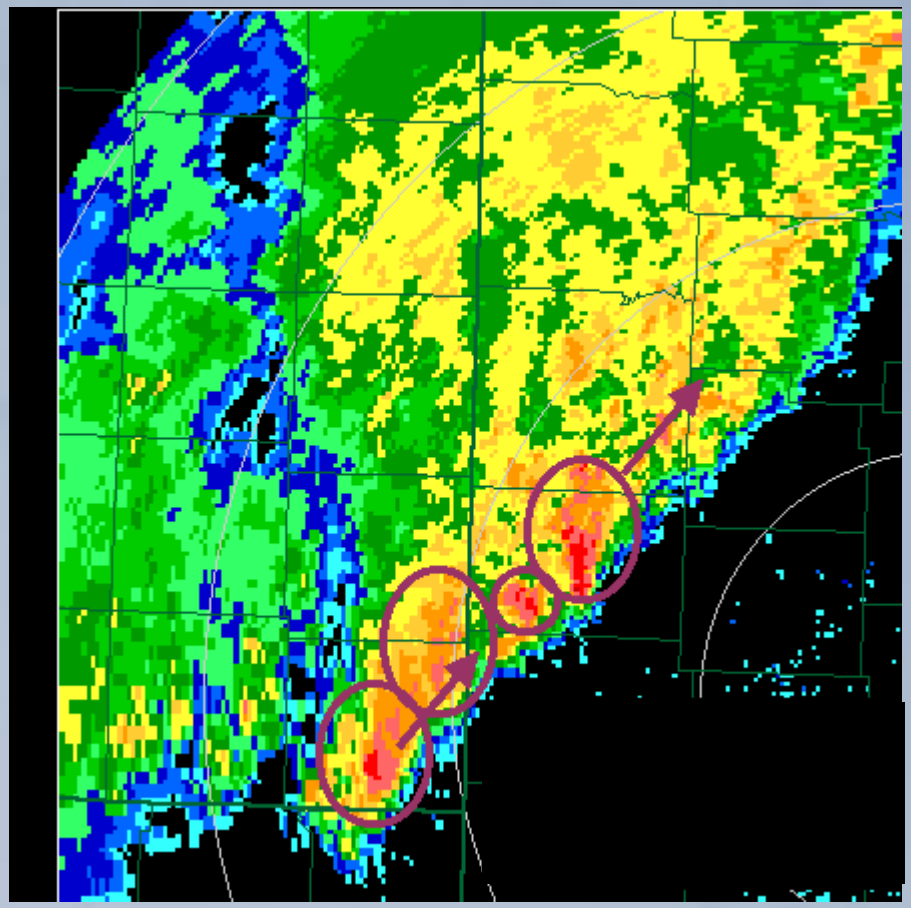
Multicellular



- Most Common
- Series of thunderstorms that move as one unit
- Can be a cluster or a line
- Can produce severe weather

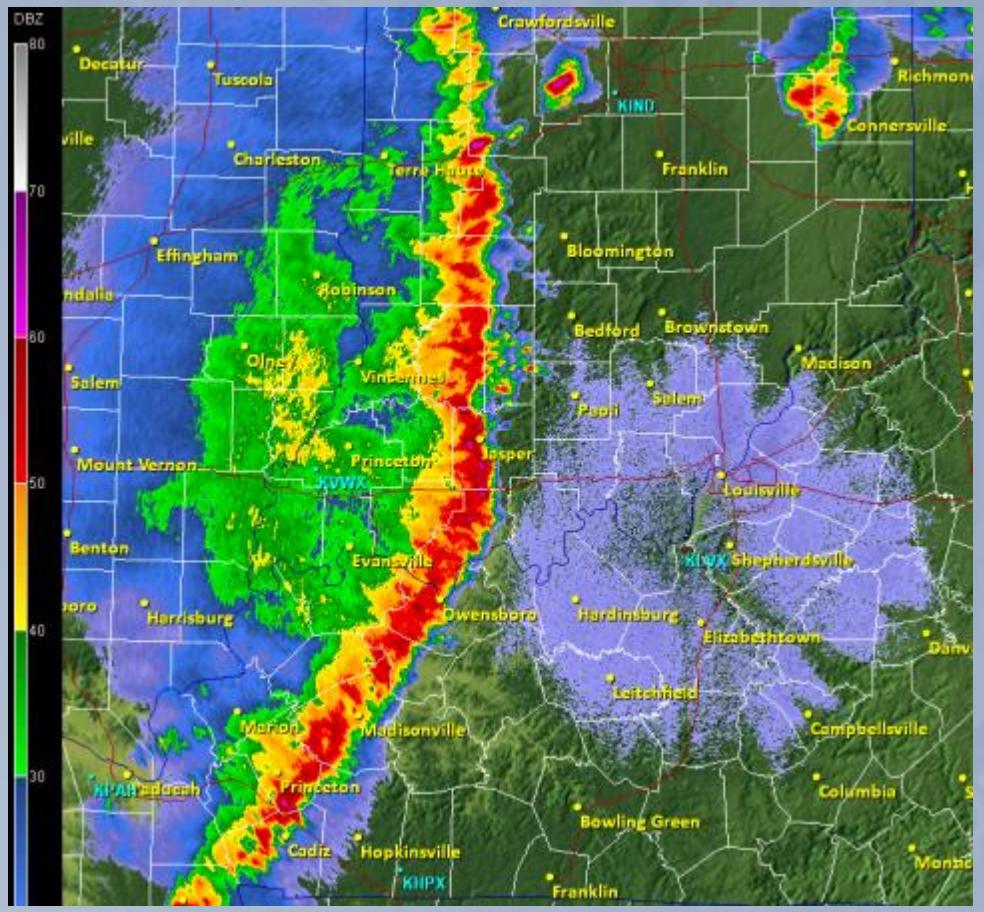
Types of Thunderstorms

Multicellular



Cluster

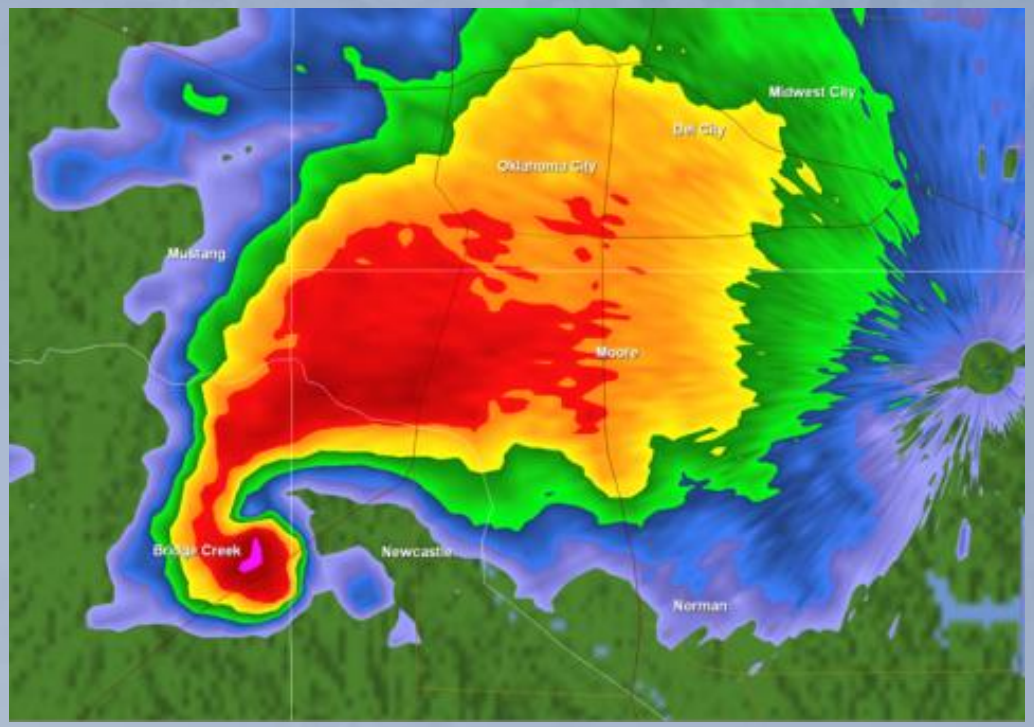
Squall Line



Types of Thunderstorms

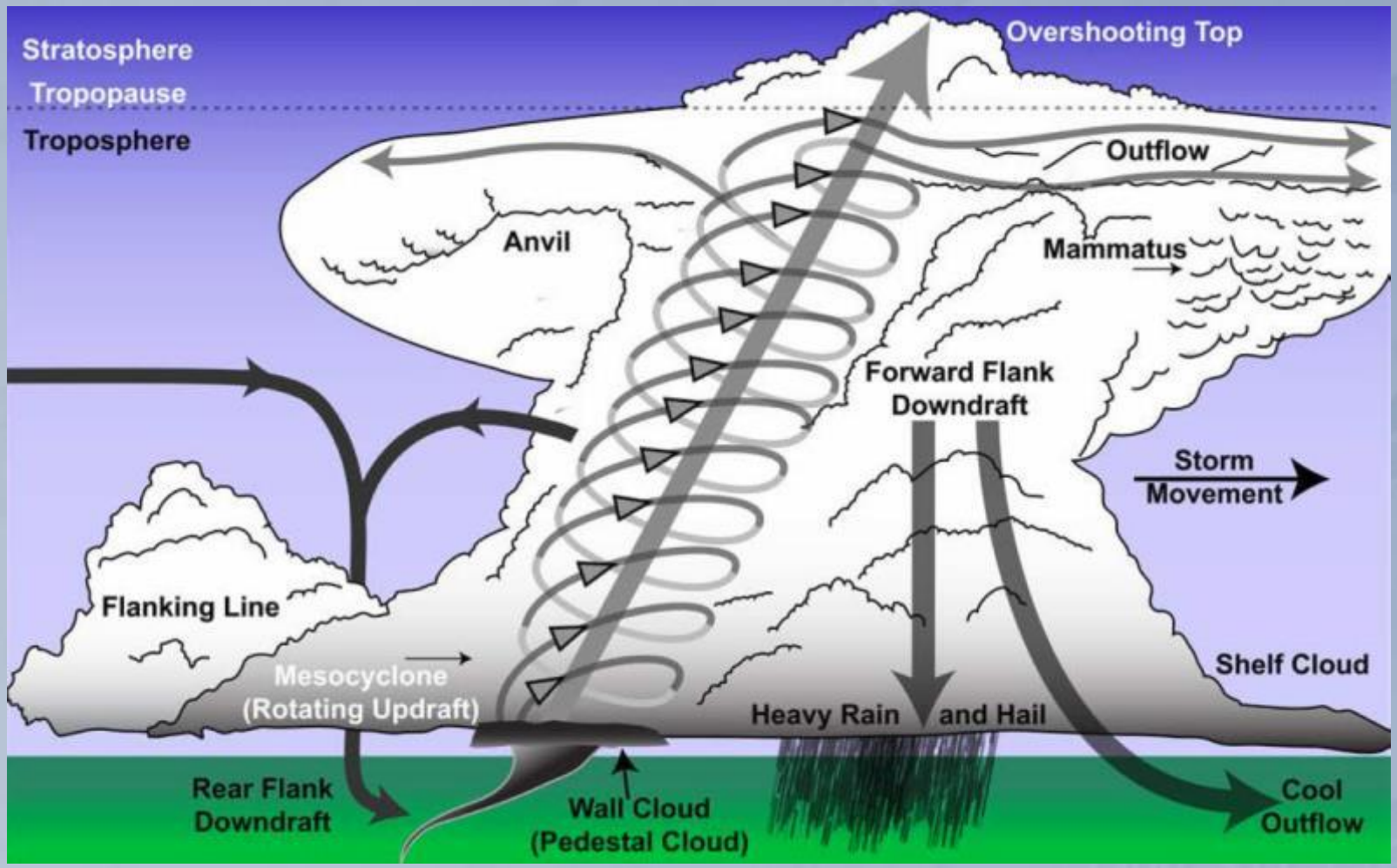
Supercells

- **Rare**
- **Long Lived**
- **Very strong & persistent updrafts**
- **Strong mesocyclone**
- **<u>Severe weather producer!</u>**

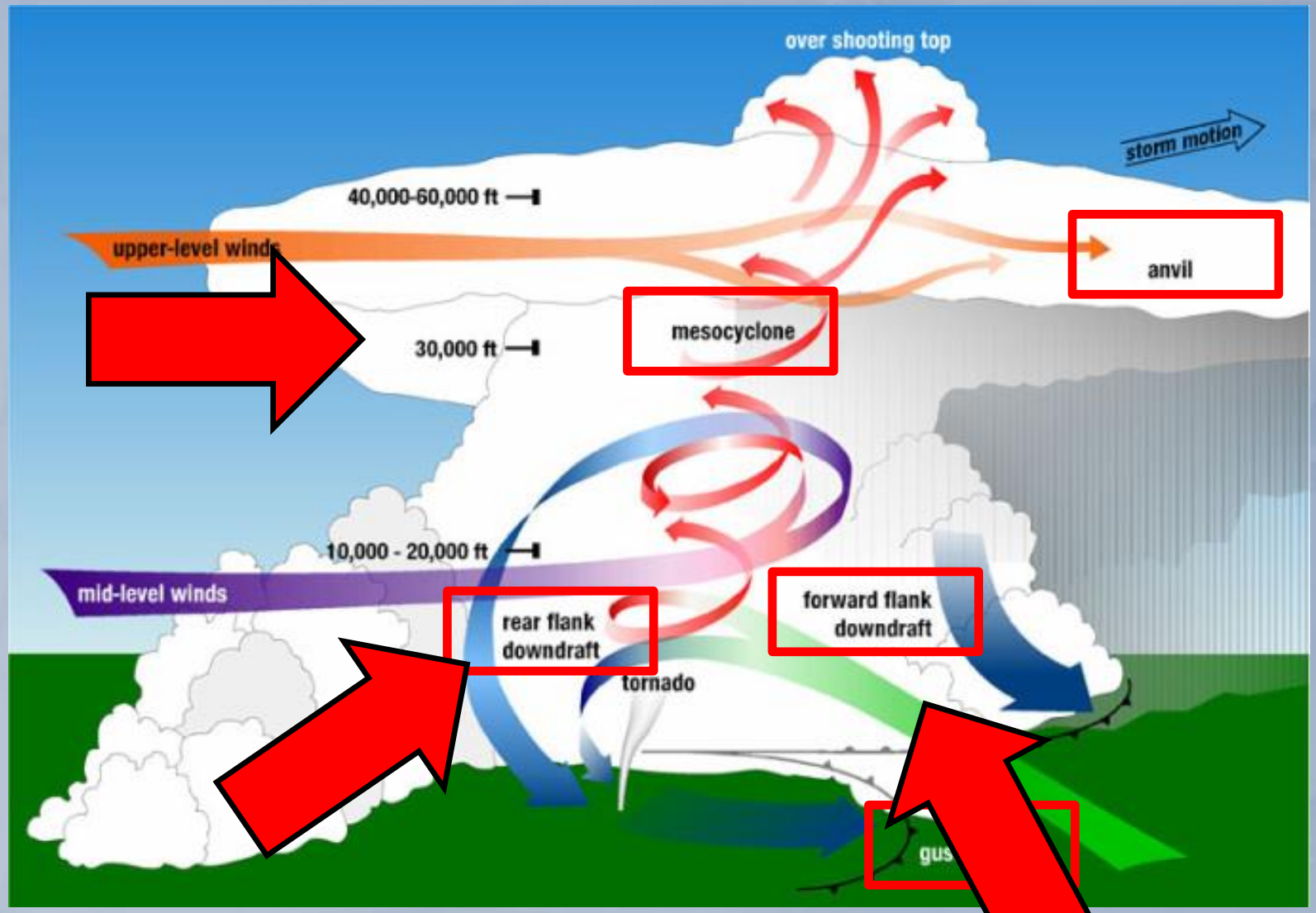


Mesocyclone: rotation within the storm

What is the Difference Between an Ordinary Thunderstorm and a Supercell?



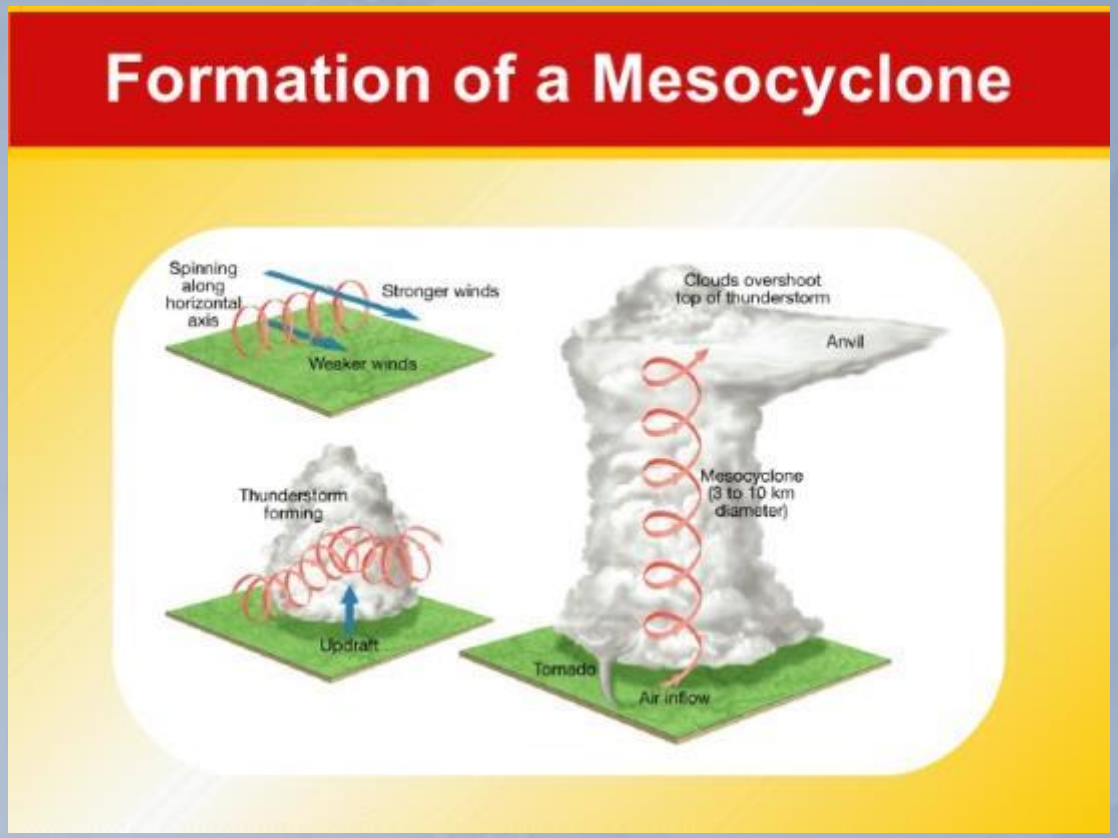
Anatomy of a Supercell



Mesocyclone

A storm-scale region of rotation, typically around 2-6 miles in diameter

A radar term, the rotation signature appearing on Doppler radar that meets specific criteria for magnitude, vertical depth, and duration.



Anvil

The core of the updraft has the strongest vertical velocity. Air will rise until it reaches a stable layer (in the case of a severe thunderstorm, the tropopause).

When the moisture/air reaches the stable layer, it spreads out in the direction of the steering flow, forming the "anvil".

A strong enough updraft will "punch" through the stable layer due to momentum, resulting in an "overshooting top"

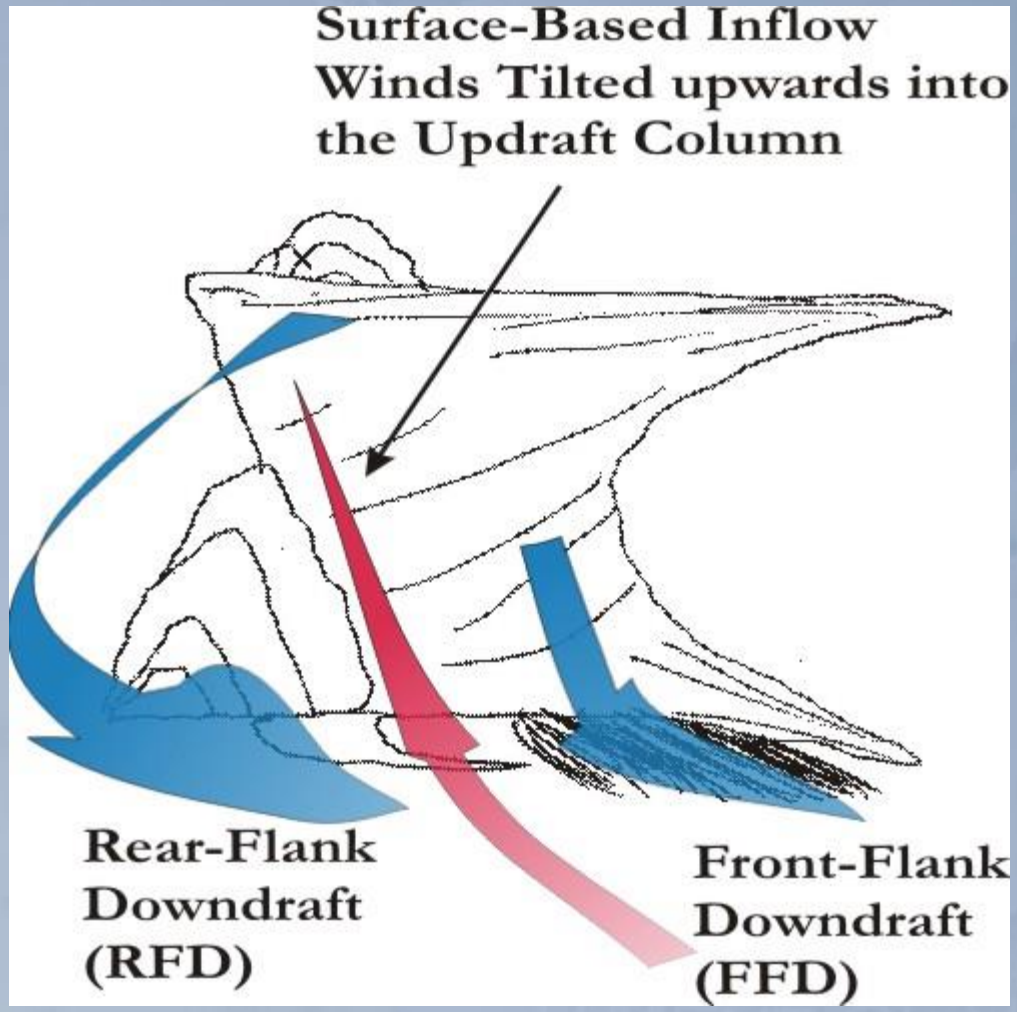
Forward Flank Downdraft

Associated with heaviest precipitation core

Results from evaporational cooling of air (moist, cool air). The temperature difference between these air particles and the ambient air causes the downdraft.

Forms in the forward flank (with respect to storm motion)

As it hits the surface, it spreads out, forming a gust front

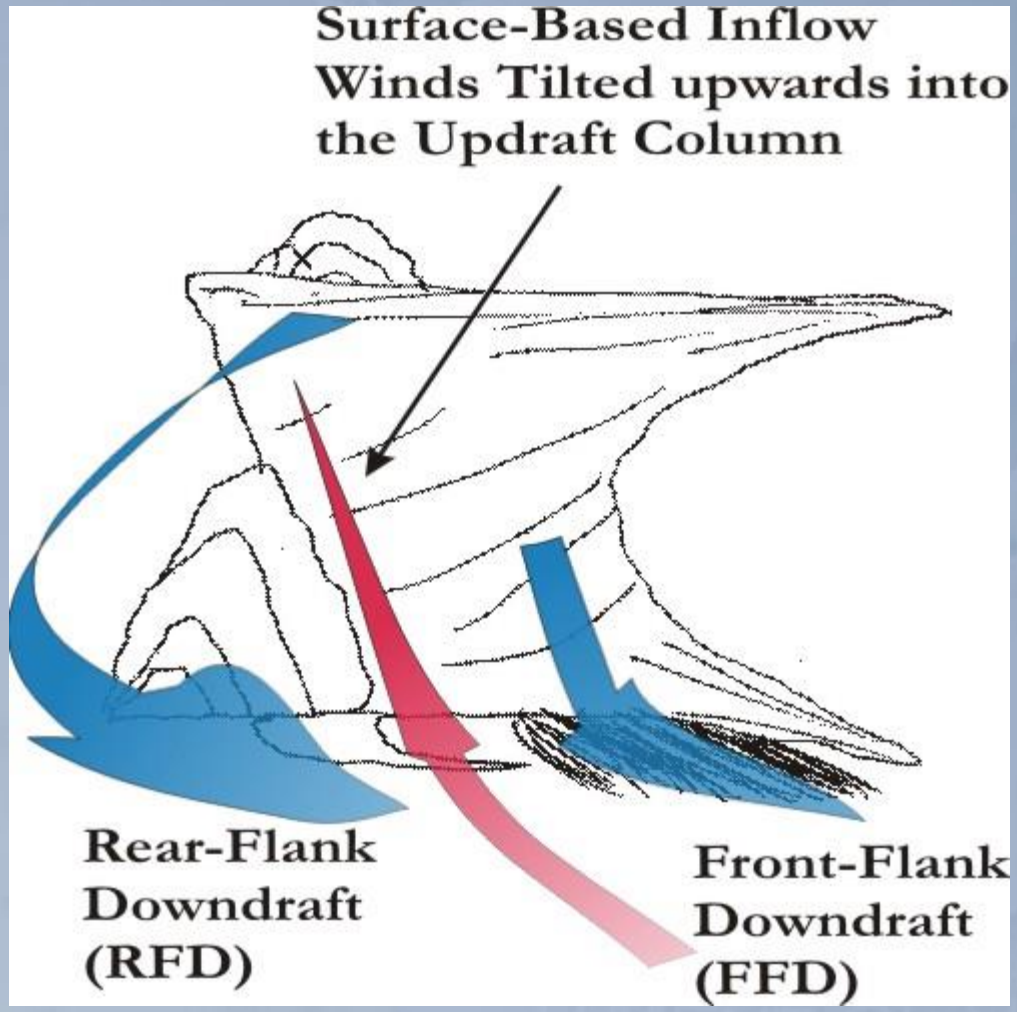


Rear Flank Downdraft

A region of dry air wrapping around the back of a mesocyclone in a supercell thunderstorm.

Warm, dry air forced down from the mid-levels of the atmosphere by vertical pressure differences.

Visible as a clear slot on radar. Scattered large precipitation particles (rain and hail) at the interface between the clear slot and wall cloud may show up on radar as a hook or pendant; thus the presence of a hook or pendant may indicate the presence of an RFD.



Wall Clouds

A localized, persistent, often abrupt lowering from a rain-free base (under the updraft)

Can range from a fraction of a mile up to nearly five miles in diameter

Normally found on the south or southwest (inflow) side of the thunderstorm.

Wall clouds don't necessarily rotate, but when they do, warn of the potential for tornadoes

Shelf Clouds

A low, horizontal wedge-shaped cloud, associated with a thunderstorm gust front (or occasionally with a cold front, even in the absence of thunderstorms).

A rising cloud motion often can be seen in the leading part of the shelf cloud, while the underside often appears turbulent, boiling, and wind-torn.

Difference between Shelf and Wall Clouds

Shelf vs. Wall

Slopes away from precip.

Indication of outflow/downdraft.

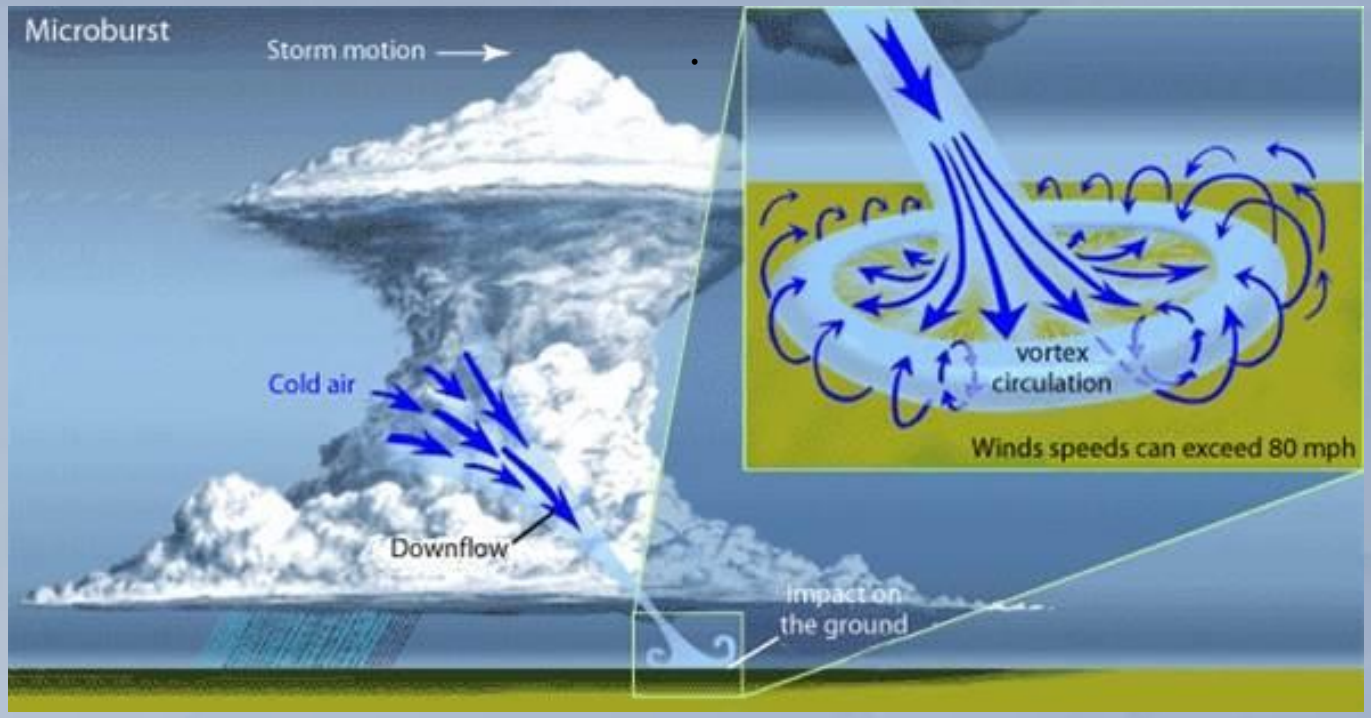
Accompanied by horizontal turbulent motions.

Slopes toward precip.

Indication of inflow/updraft.

Accompanied by vertical rotation.

Microbursts



A localized column of sinking air within a thunderstorm and is usually less than or equal to 2.5 miles in diameter. Microbursts can cause extensive damage at the surface, and in some instances, can be life-threatening.

When the updraft is no longer capable of holding the large core of rain/hail up in the thunderstorm, the core plummets to the ground. As it hits the ground it spreads out in all directions

Types of Supercells

Classic

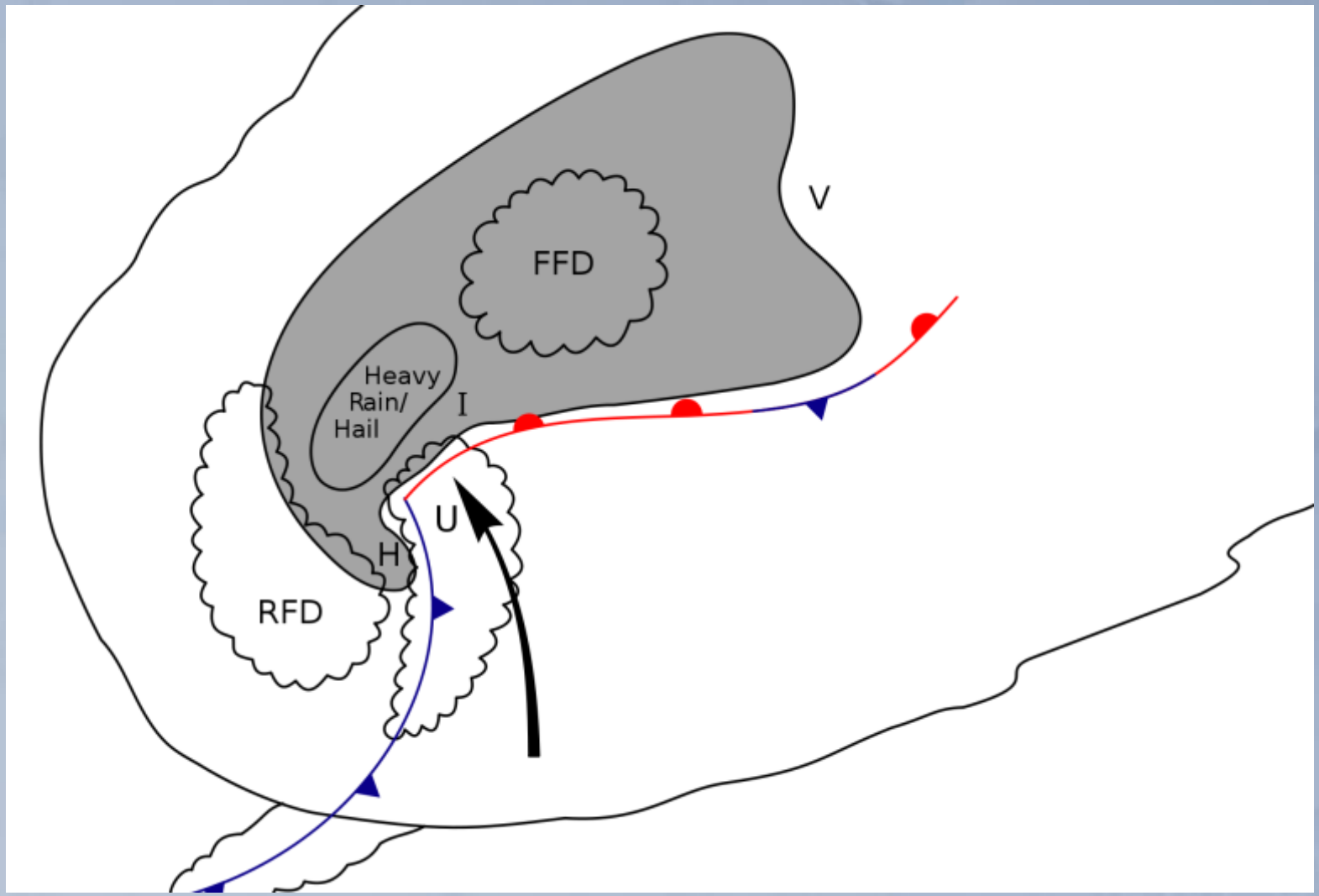
High Precipitation (HP)

Low Precipitation (LP)

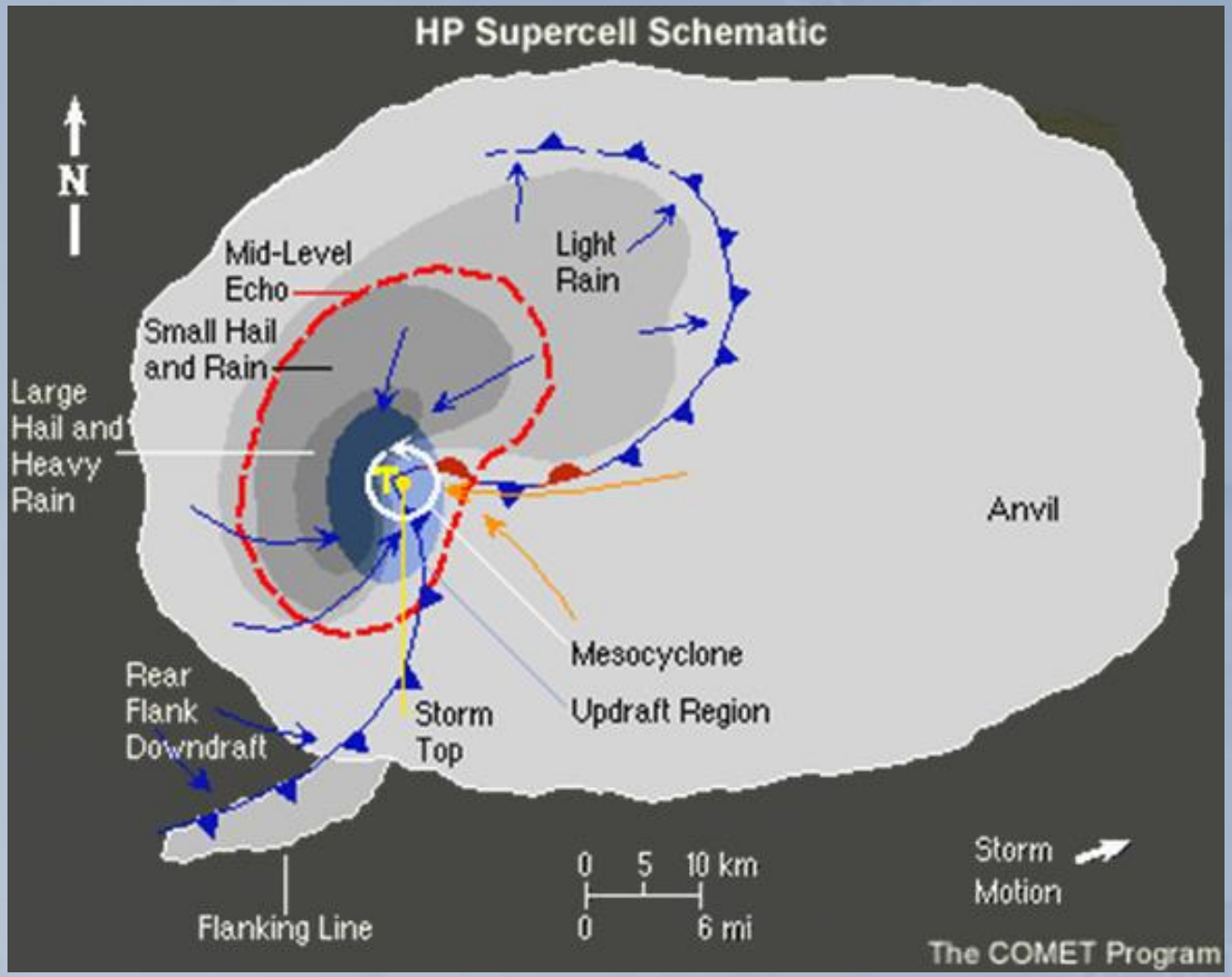
Types of Supercells

Classic	HP	LP
- Best indication of a hook on radar - Varying degrees of hail, winds and tornadoes - Some precipitation but not extremely heavy	- Heavy precipitation, most likely to produce flash flooding (rain-wrapped supercells) - May or may not have a recognizable hook echo on radar - Smaller hail - Often embedded with squall lines	- Little or no precipitation - Large hail and strong straight line winds - Weaker tornadoes (if they do occur). But clearly show rotation - Higher based, clear base

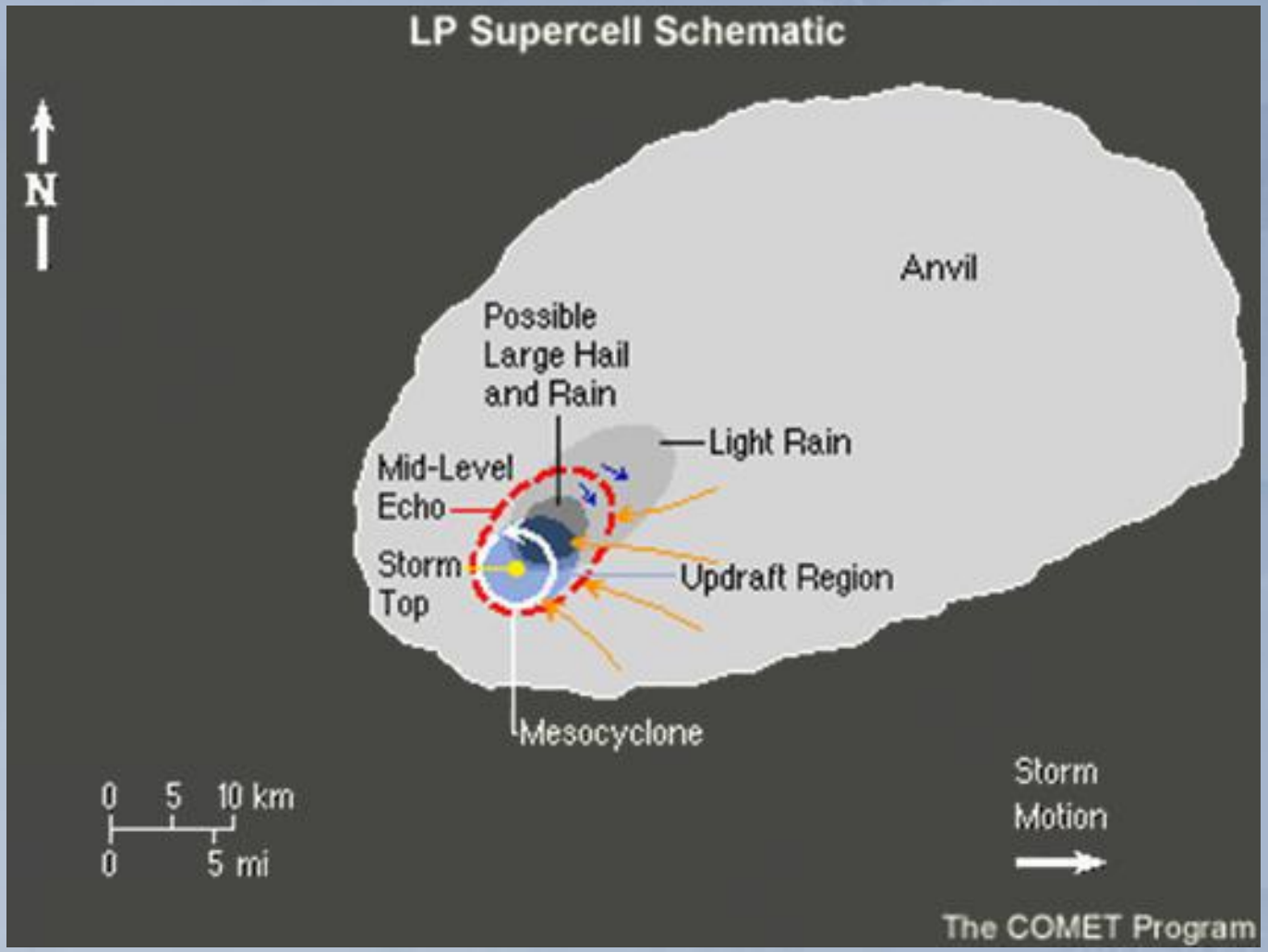
Classic



HP


HP Supercell Schematic
N
Mid-Level Echo
Small Hail and Rain
Large Hail and Heavy Rain
Light Rain
Anvil
Mesocyclone
Updraft Region
Storm Top
Rear Flank Downdraft
Flanking Line
0 5 10 km
0 6 mi
Storm Motion
The COMET Program

LP

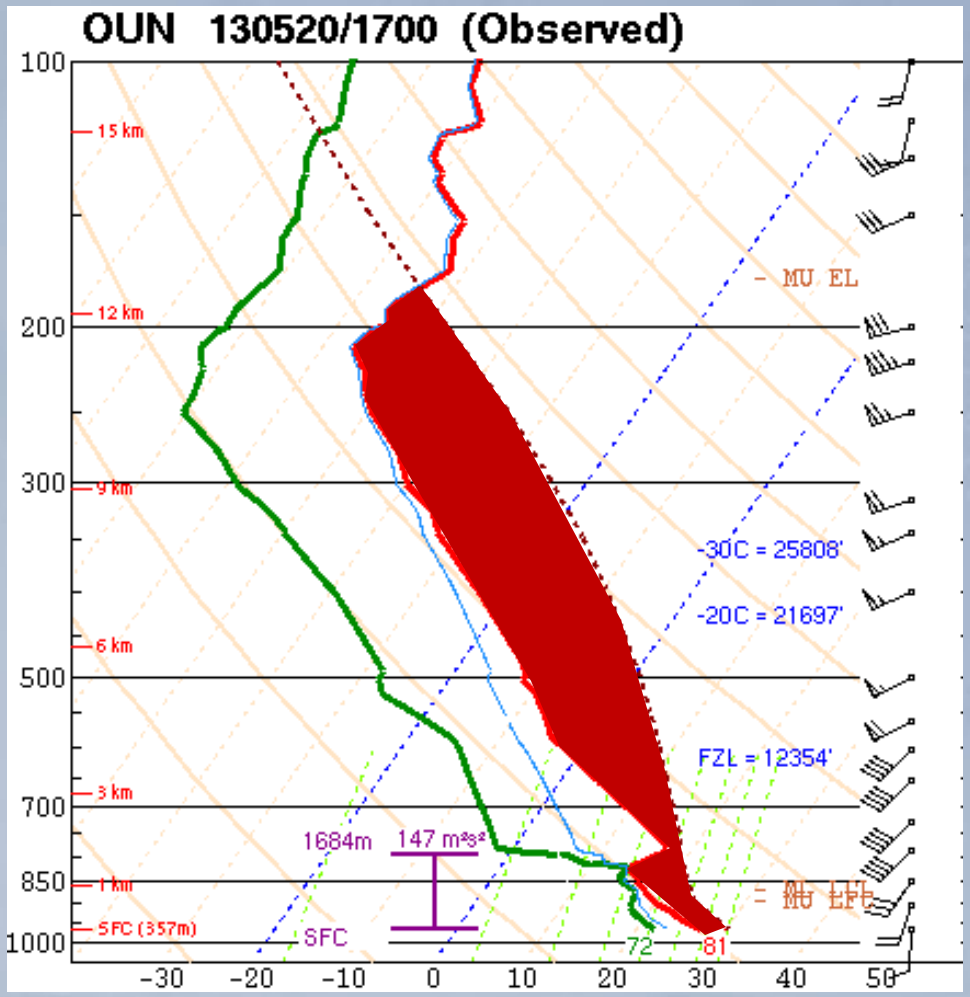

LP Supercell Schematic
N
Anvil
Possible
Large Hail
and Rain
Light Rain
Mid-Level
Echo
Storm
Top
Updraft Region
Mesocyclone
0 5 10 km
0 5 mi
Storm
Motion
The COMET Program

Supercell Ingredients

- **Lift** - A lifting mechanism to focus the energy
- **Instability** - Heat and moisture
- **Shear** - Increasing winds with height and veering winds with height

Instability

CAPE = Convective Available Potential Energy



Sounding 3 hours before 2013 Moore EF-5 Tornado

> 3000 J/kg Mixed Layer CAPE!!

Instability Indices

Index	Weak potential	High potential
Lifted Index	0 to -2	- 6 or less
CAPE	500-1000	> 2500
Total Totals	48 to 49	> 52
Sweat	200 - 300	> 400

Types of Wind Shear

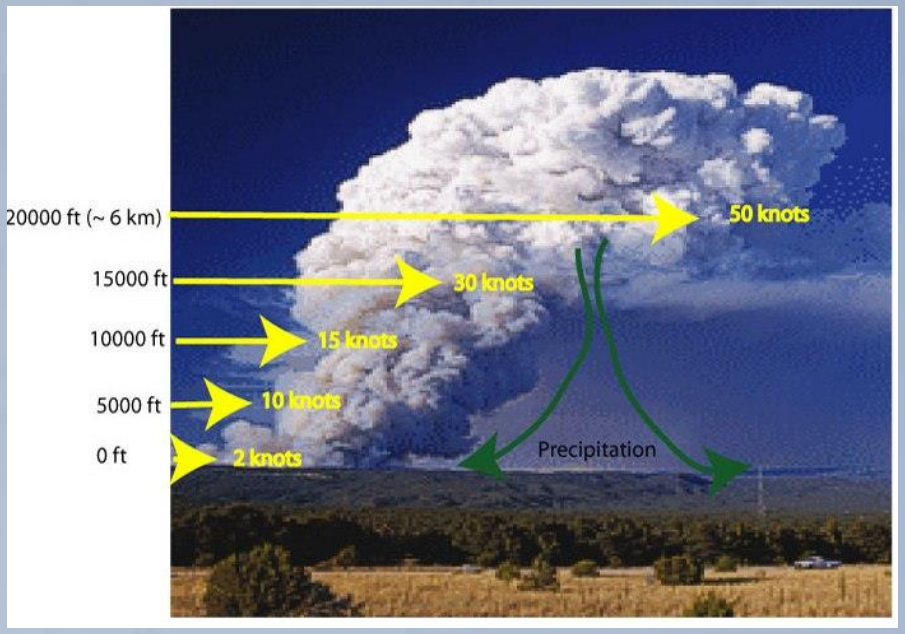
- **Directional Shear** – Winds changing direction with height

- **Speed Shear** – Changing wind speeds with height

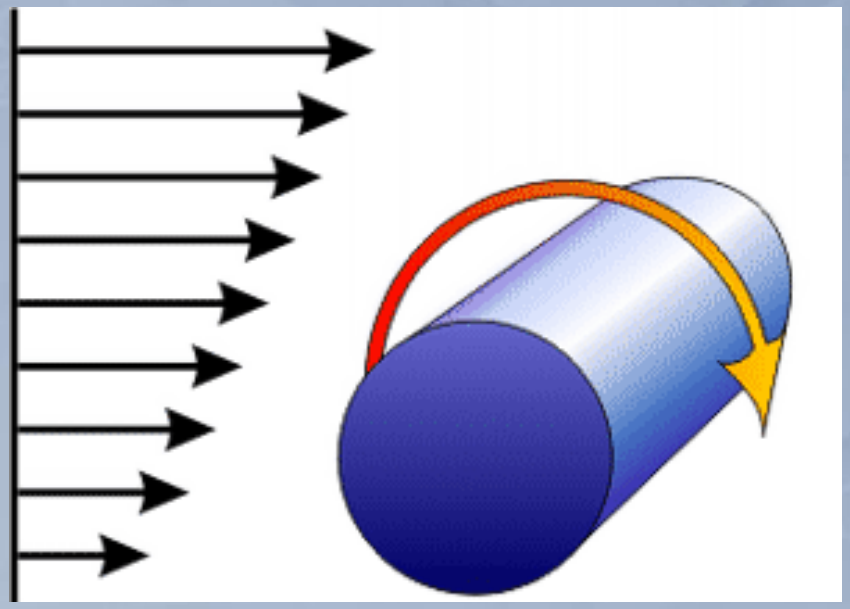
Types of Wind Shear

Directional Shear

Types of Wind Shear

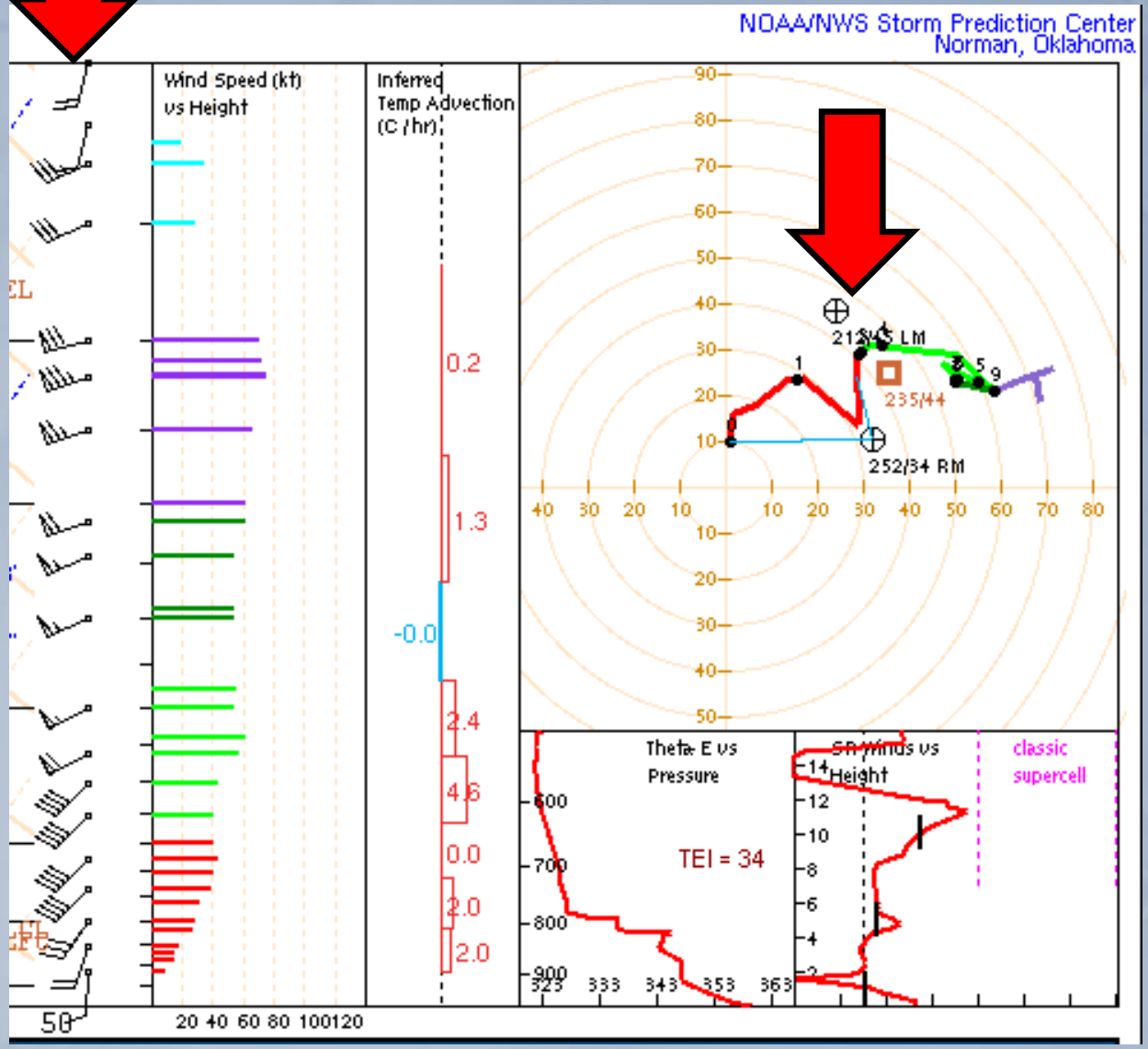


Speed Shear



Vertical wind shear creates a "spin" in the atmosphere.

Wind Shear



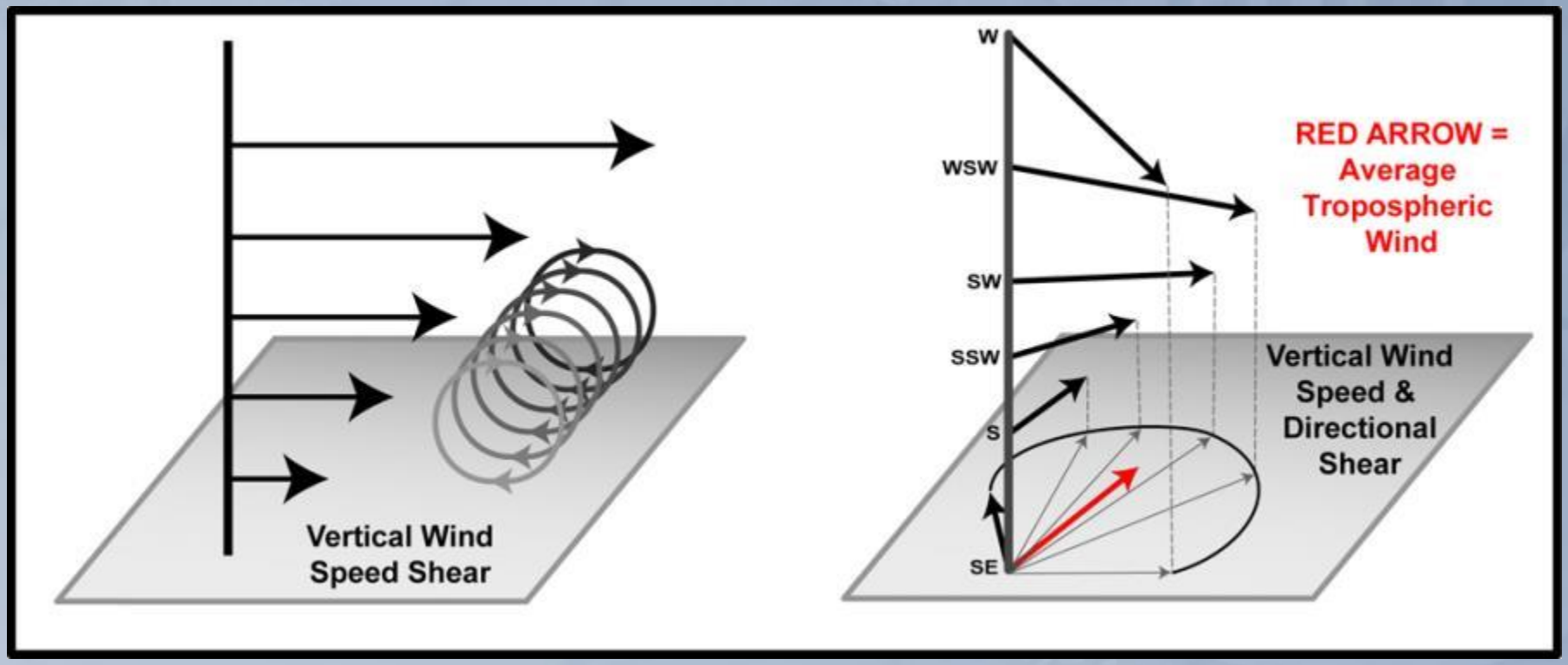
Sounding 3 hours before 2013 Moore EF-5 Tornado

Wind Shear Indices

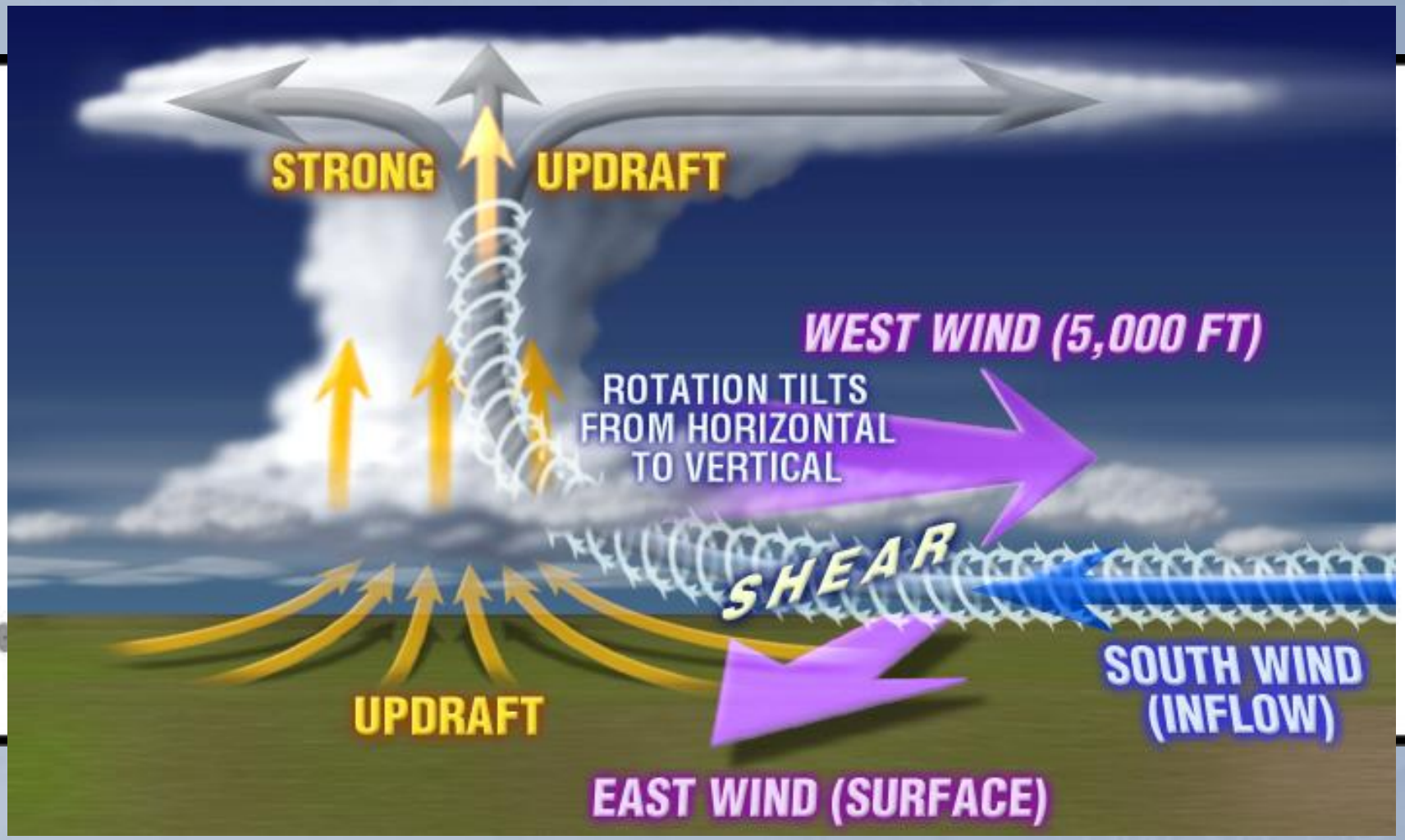
Index	Weak potential	High potential
Storm Relative Helicity	65 to 125	300 or more
Vertical Shear	< 30	40 or more
Storm Inflow	15 mph	25 or more
Storm Motion	15 to 30 mph	40 or more

Wind Shear and Tornadoes

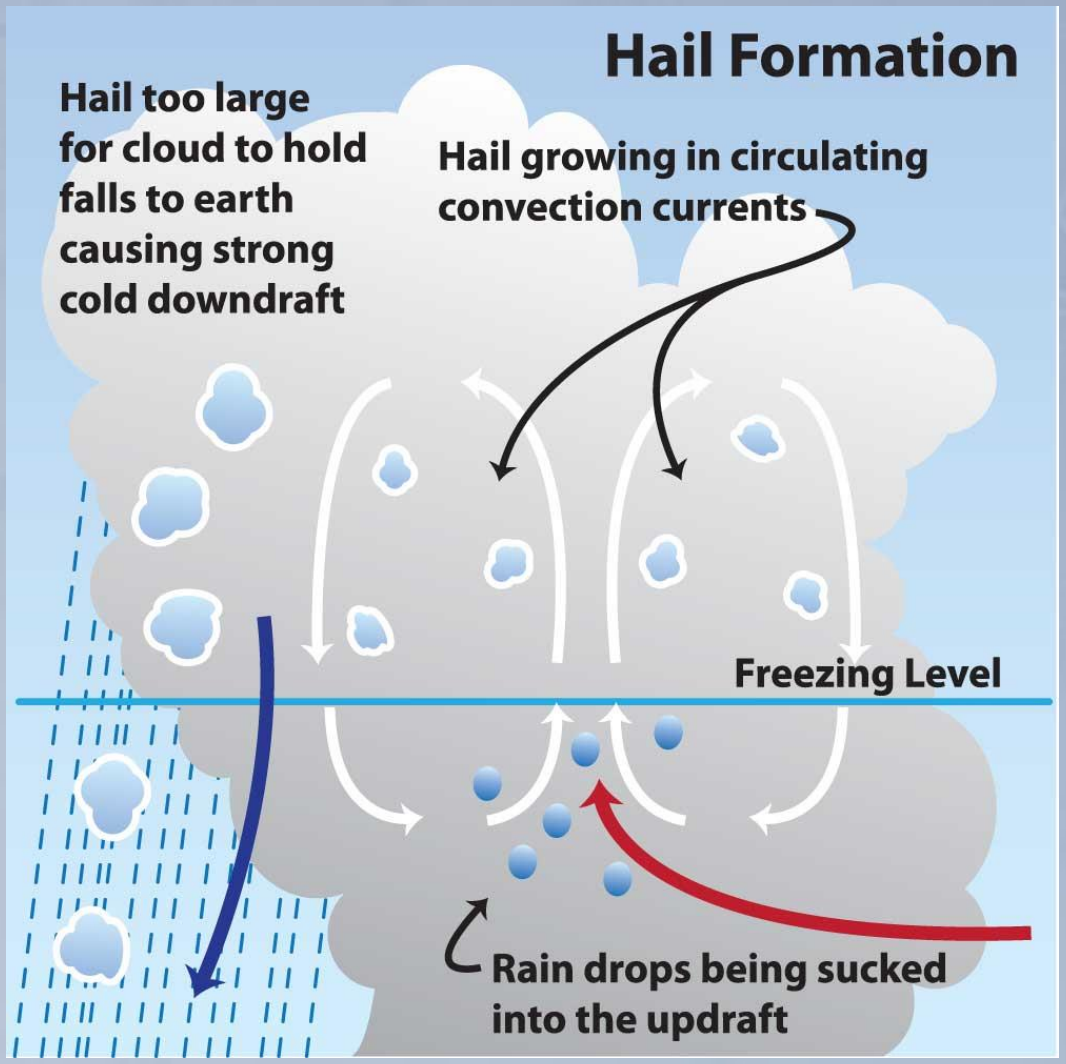
For tornadogenesis: You need strong vertical wind shear, both directional and speed



Wind Shear and Tornadoes



How Does Hail Form?



Hail forms by a process called aggregation.

Instability and Wind Shear Indices

Index	Moderate	High
Energy Helicity Index (EHI)	0.5 to 2.0	> 3.0
Bulk Richardson Number (BRN)	10 – 15 or 35 to 50	15 to 35

Severe Thunderstorms

Warning Criteria: 1” Hail and/or 58 MPH Winds

- **Straight-Line Winds**
- **Hail**
- **Flash Flooding**
- **Tornadoes**

Radar Principals

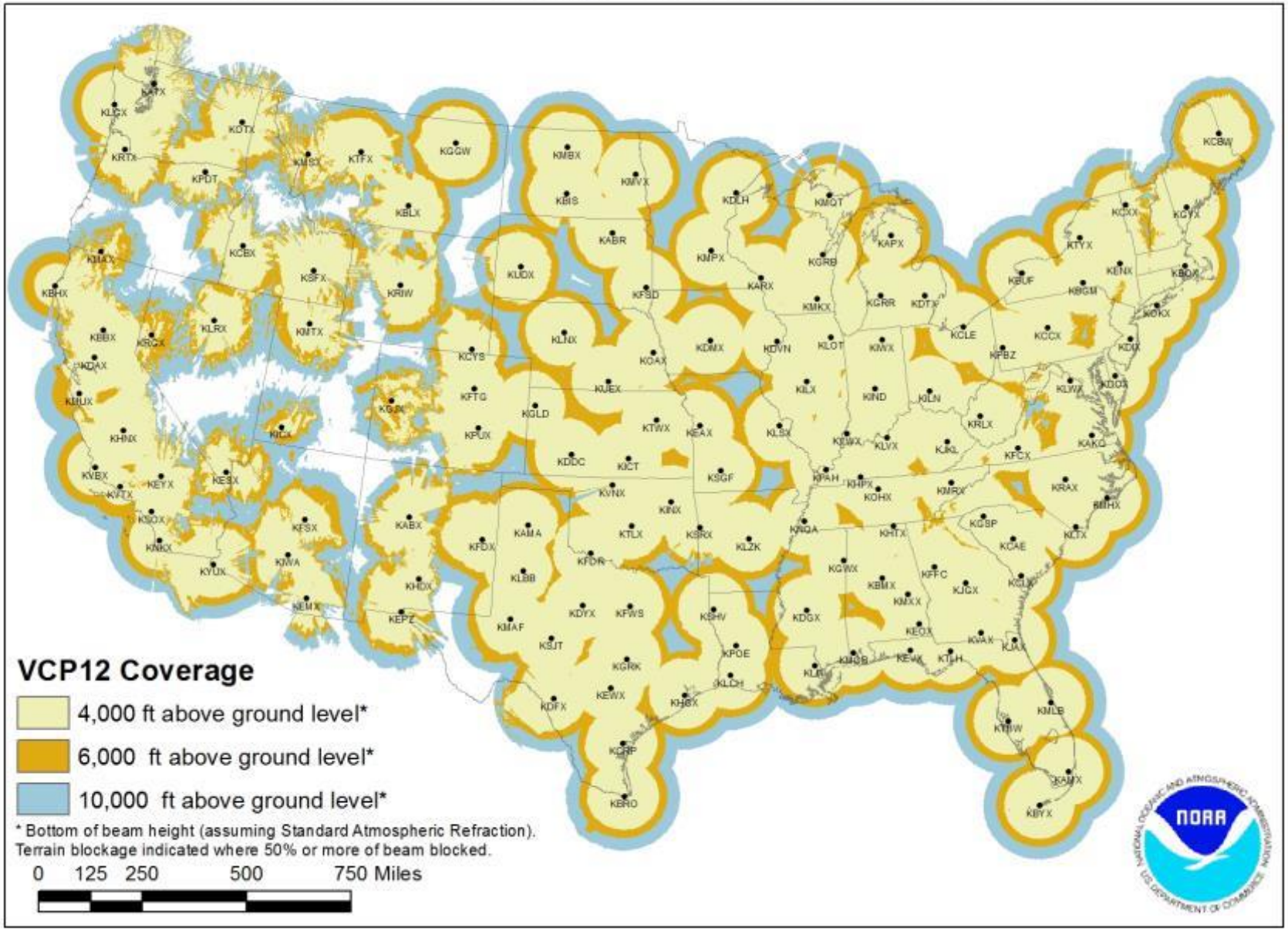
- Radar Basics
- Dual-Polarization Radar
- Reflectivity, Velocity, SRM
- Hail Indications
- Precipitation Estimates
- What Else can the Radar See?
- MRMS

Basic Radar

WSR-88D (10 cm, S-Band)

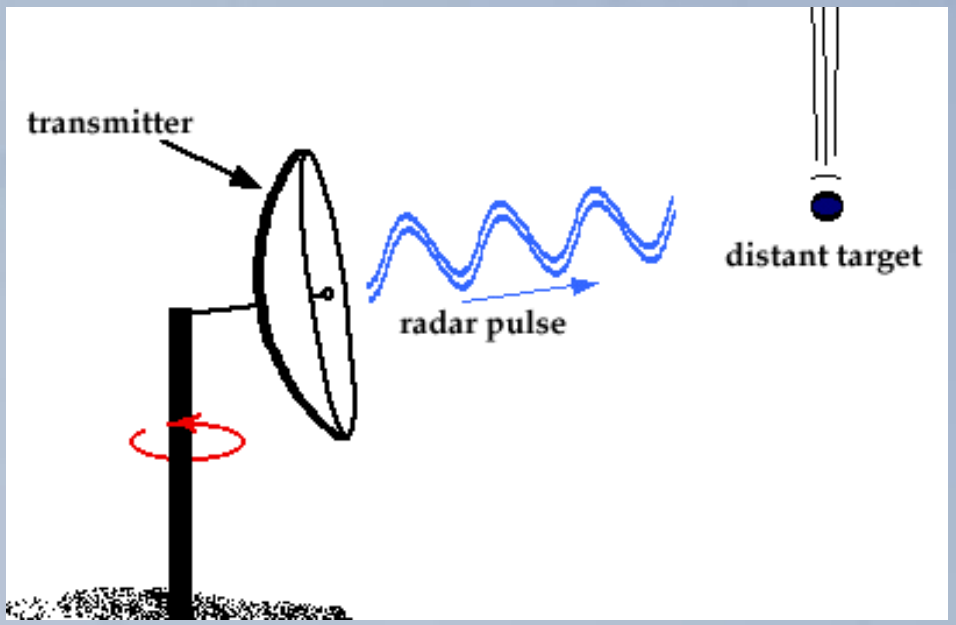
- 70 Ft Tower
- 40 Ft Dome
- 30 Ft Radar Dish
- 750 KW Power
- 1° Beamwidth
- -1-20° Elevations

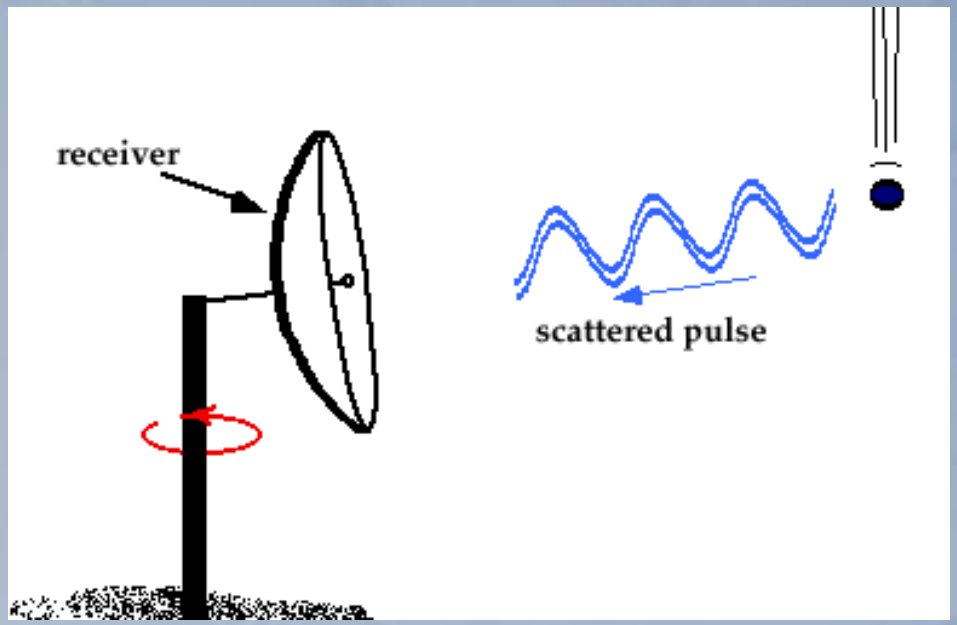
NEXRAD Coverage Below 10,000 Feet AGL



Basic Radar

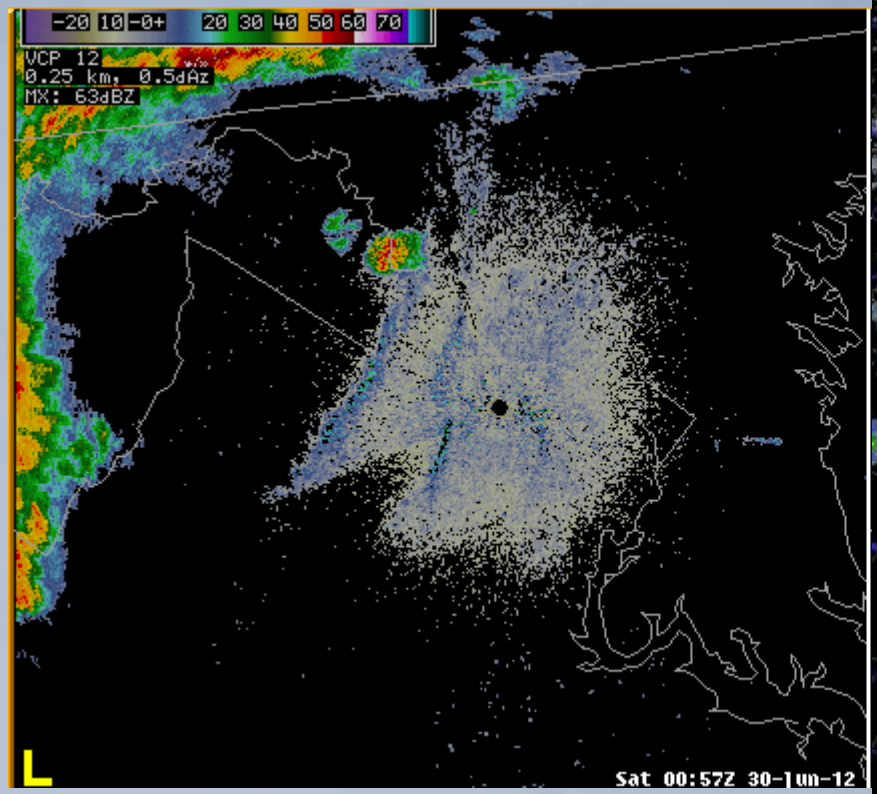
RAdio Detecting And Ranging

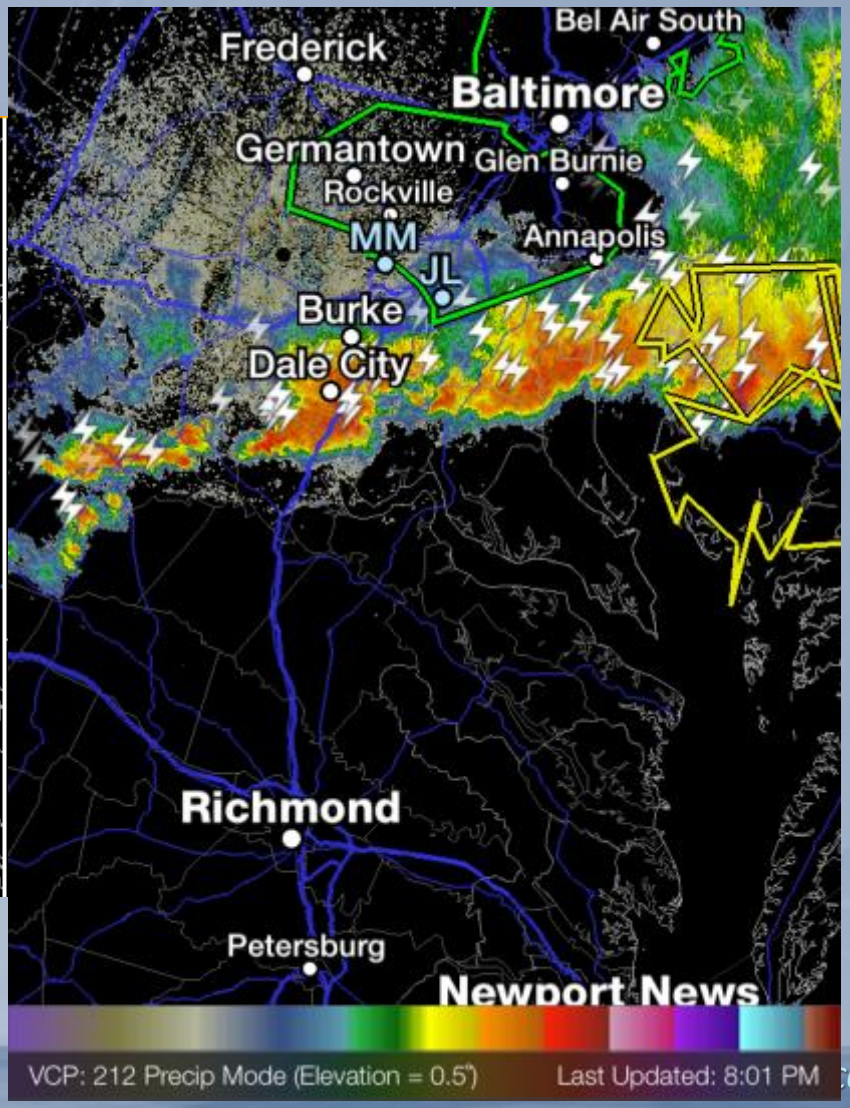




Basic Radar

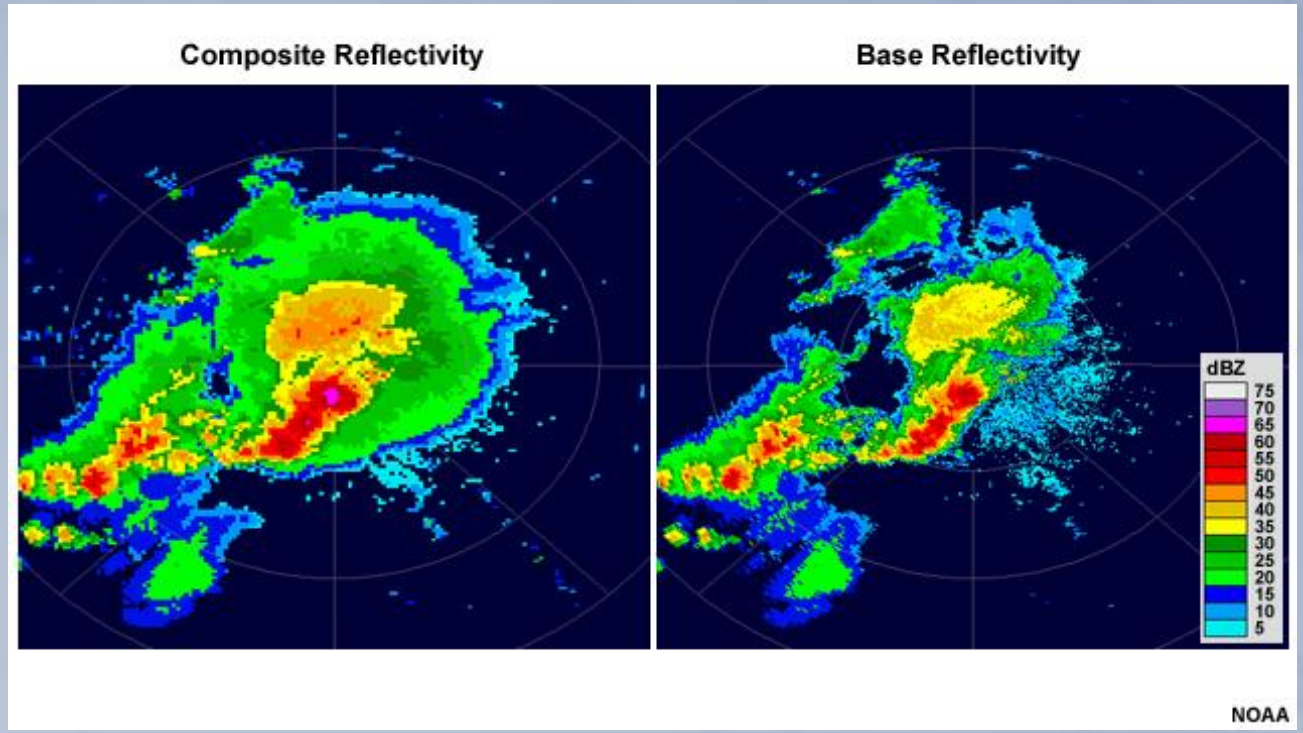
Base Reflectivity





Basic Radar

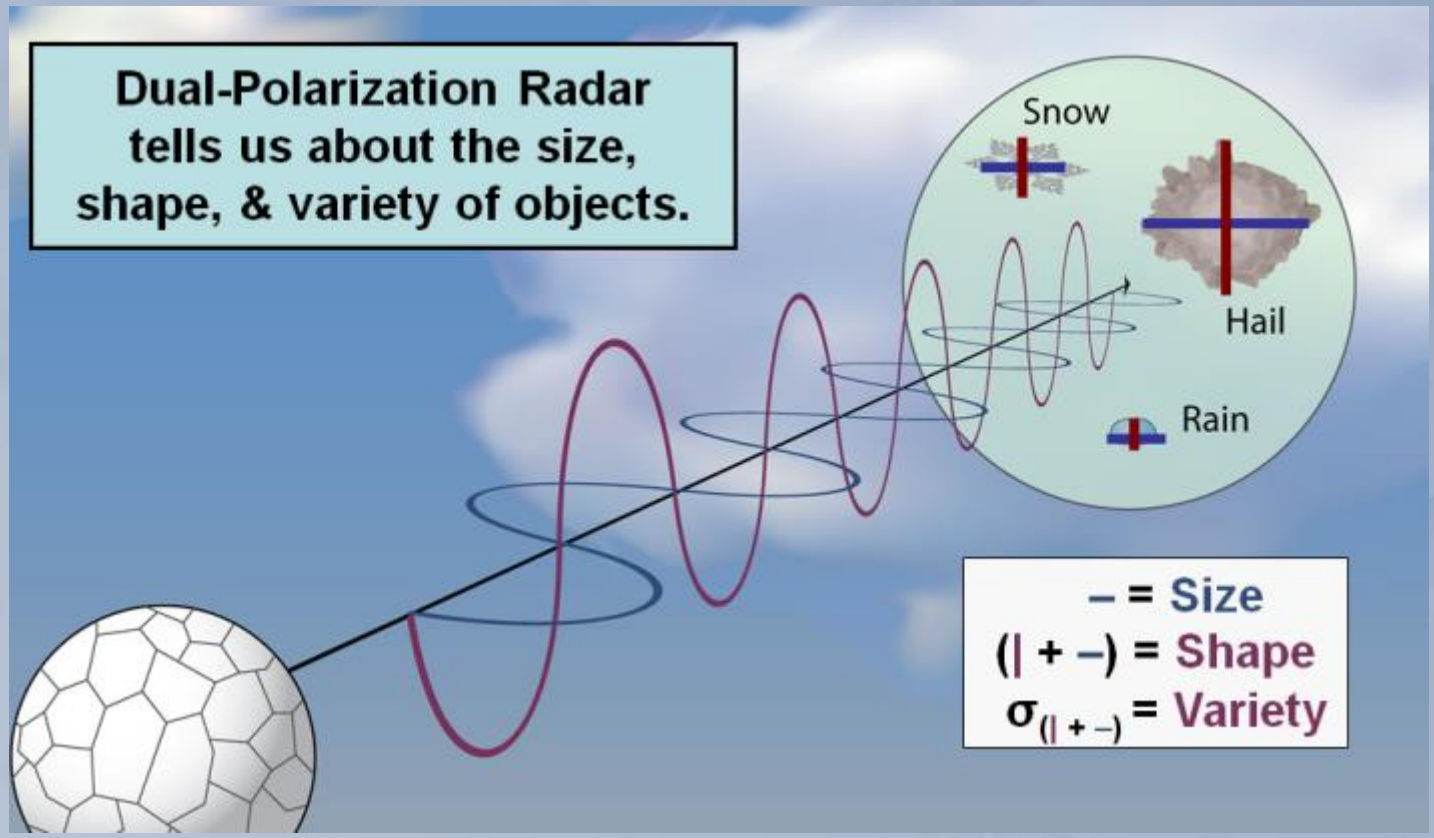
Composite Reflectivity



This display is of maximum echo intensity (reflectivity) from any elevation angle at every range from the radar.

Be careful using composite, it might mask low level features.

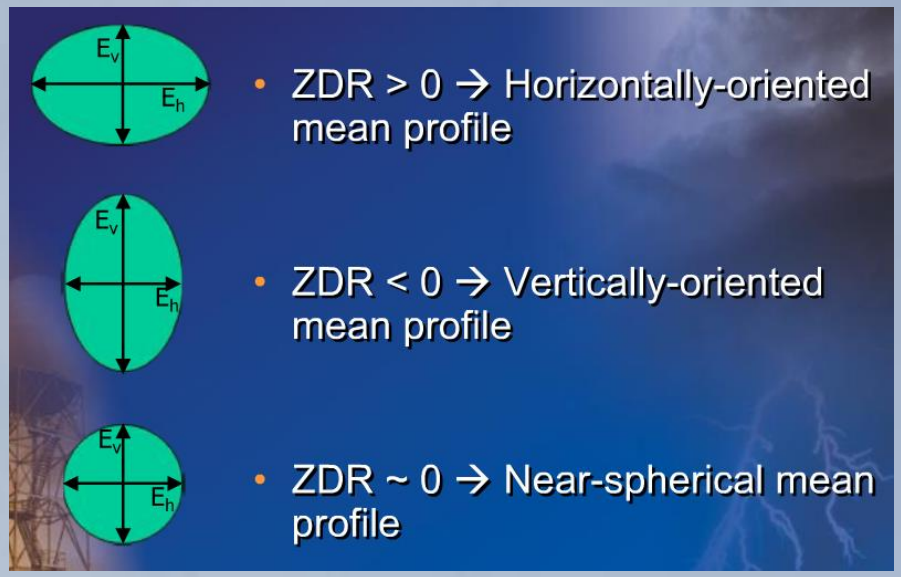
Dual - Polarization



Provides more insight into scatterers due to vertical and horizontal wavelengths

Dual - Polarization

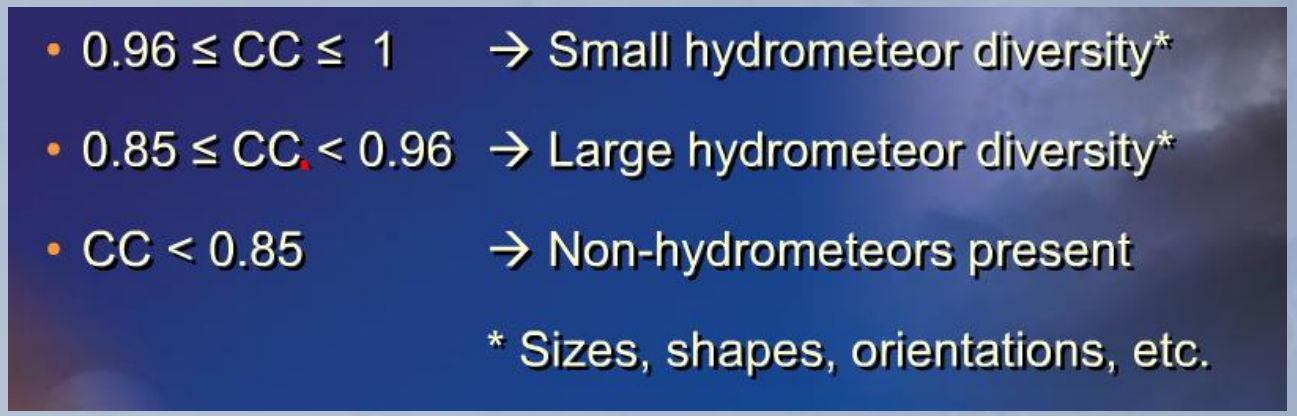
ZDR



Differential Reflectivity (Z_{DR}) is a ratio of the reflected horizontal and vertical power returns.

CC

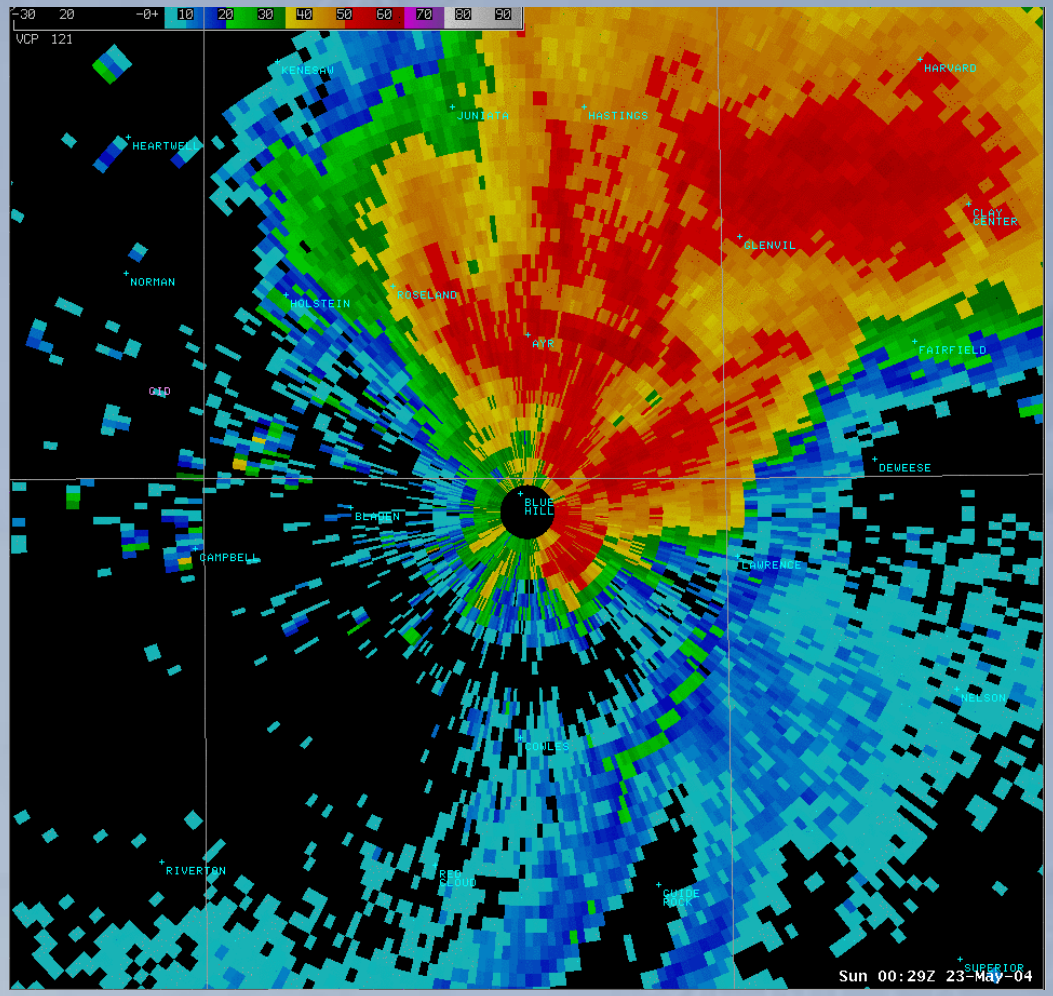
Correlation Coefficient (CC) is a measure of the diversity of scatterers within a sample volume



Basic Radar

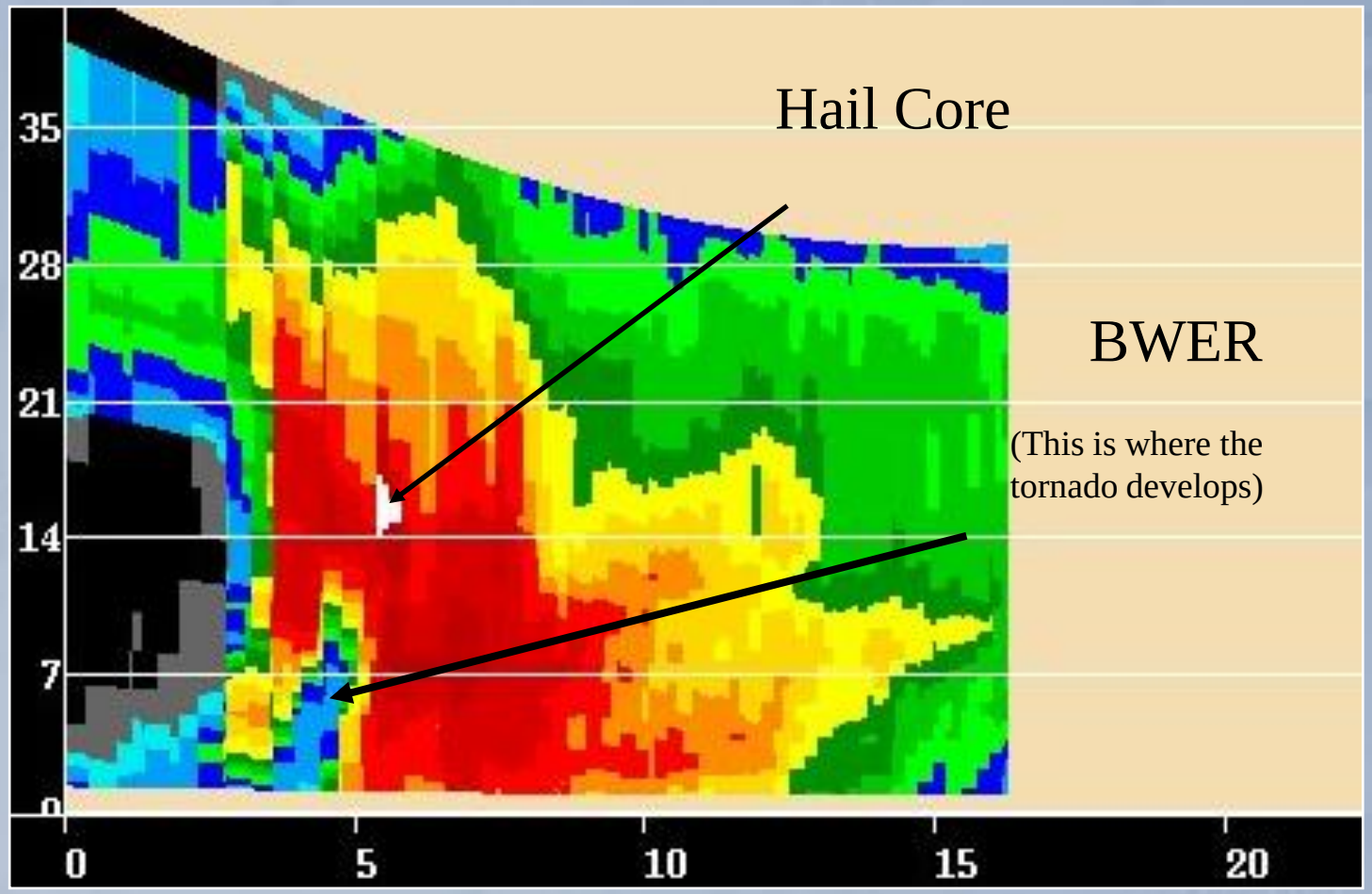
Cone of Silence

- Storm appears to weakening when approaching radar
- Storms moving away seem to get taller
- Harder to detect severe inside 10 nm
- How can we overcome the cone of silence?

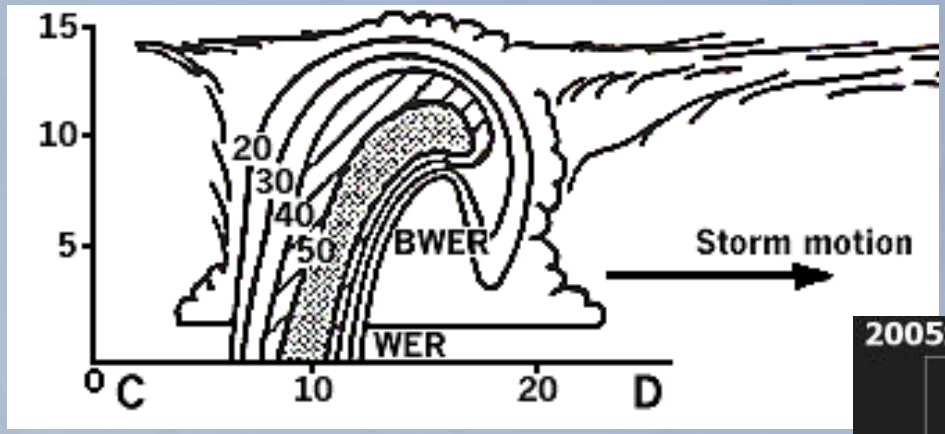


Basic Radar

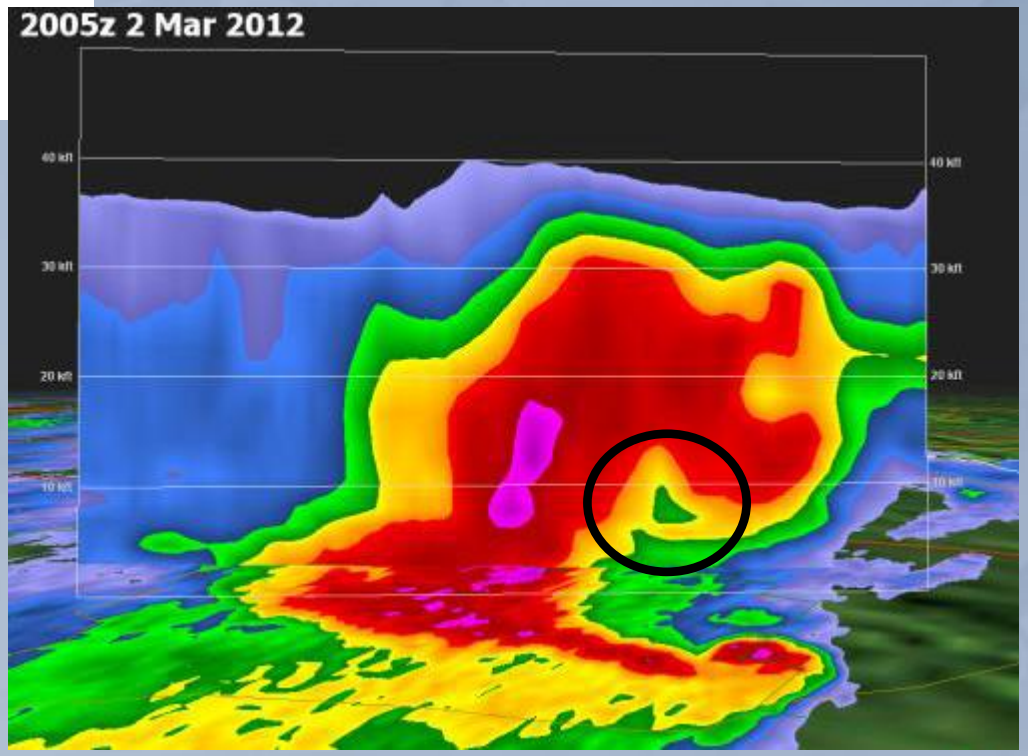
Cross Sections



WER and BWER



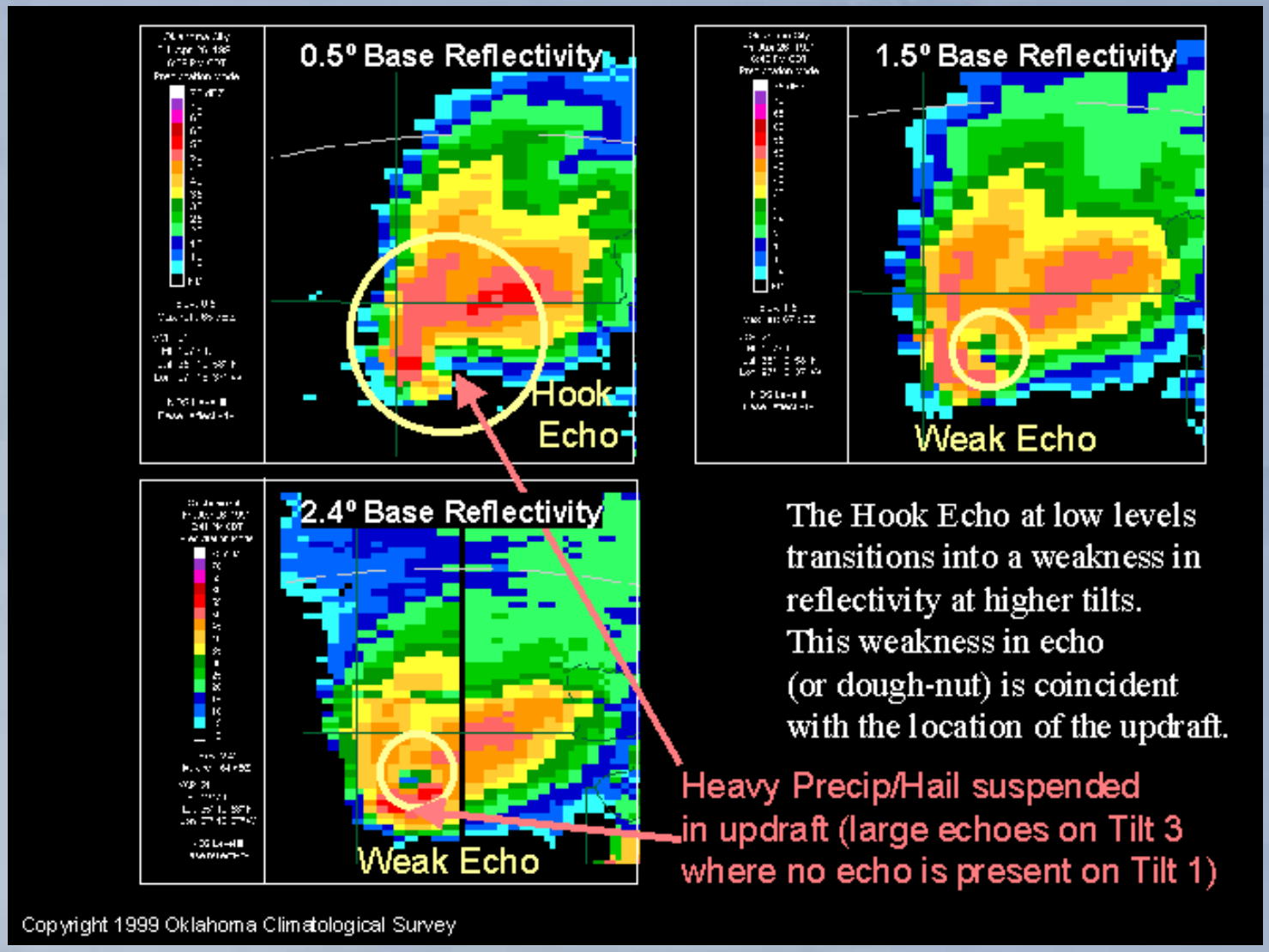
BWER location is coincident with core of mesocyclone



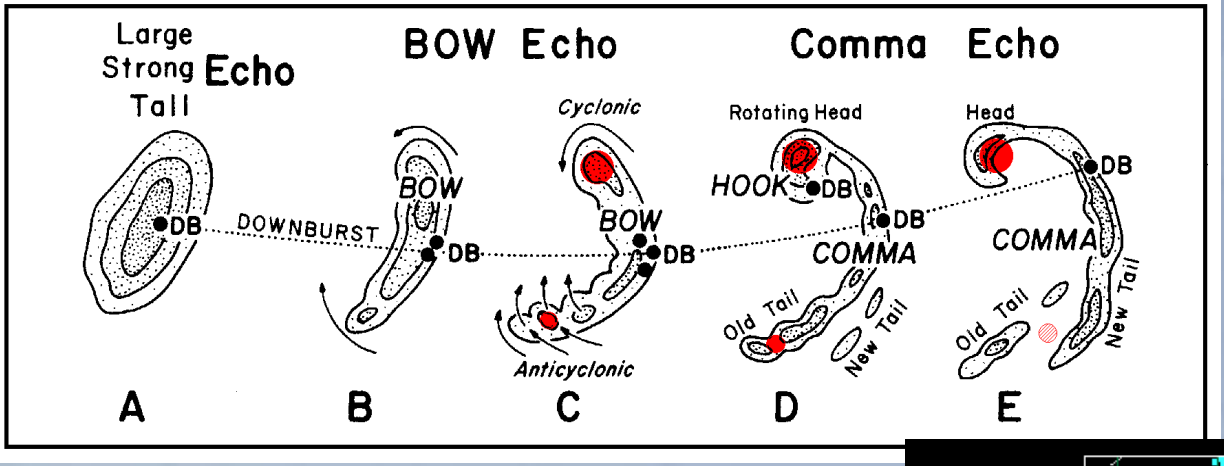
Weak echo region (WER) **is a low-level area of weak/low reflectivity on radar as strong updraft suspends and prevents precipitation from falling in this area**

Bounded weak echo region (BWER) **is a mid-level weak/low reflectivity (cavity) aloft as intense updraft suspends and prevents precipitation from forming and falling in this area.**

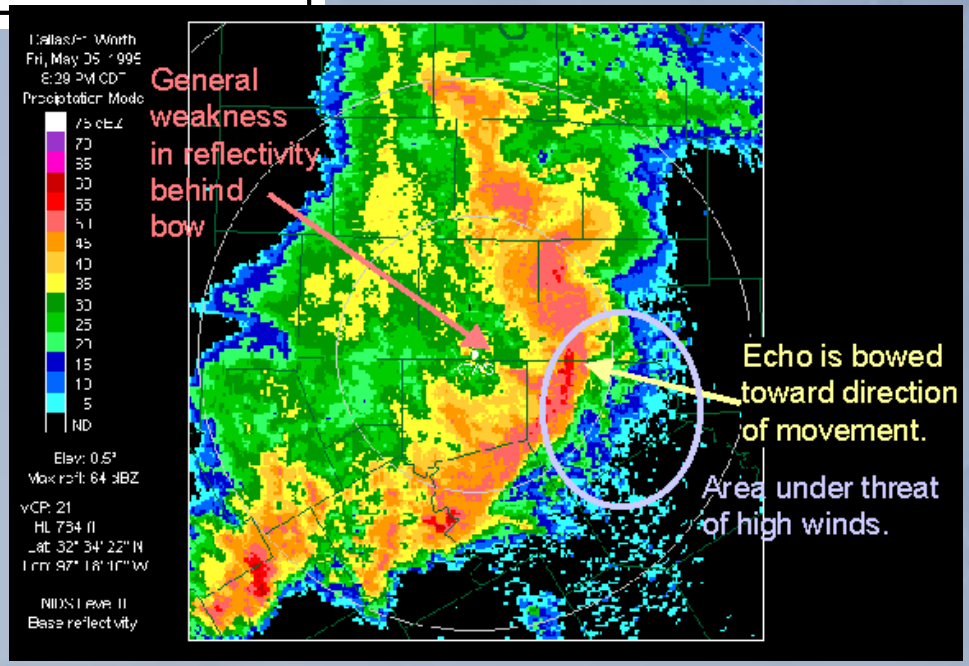
Hook Echoes


0.5° Base Reflectivity
Hook Echo
1.5° Base Reflectivity
Weak Echo
2.4° Base Reflectivity
Weak Echo
The Hook Echo at low levels transitions into a weakness in reflectivity at higher tilts. This weakness in echo (or dough-nut) is coincident with the location of the updraft.
Heavy Precip/Hail suspended in updraft (large echoes on Tilt 3 where no echo is present on Tilt 1)
Copyright 1999 Oklahoma Climatological Survey

Bow Echoes



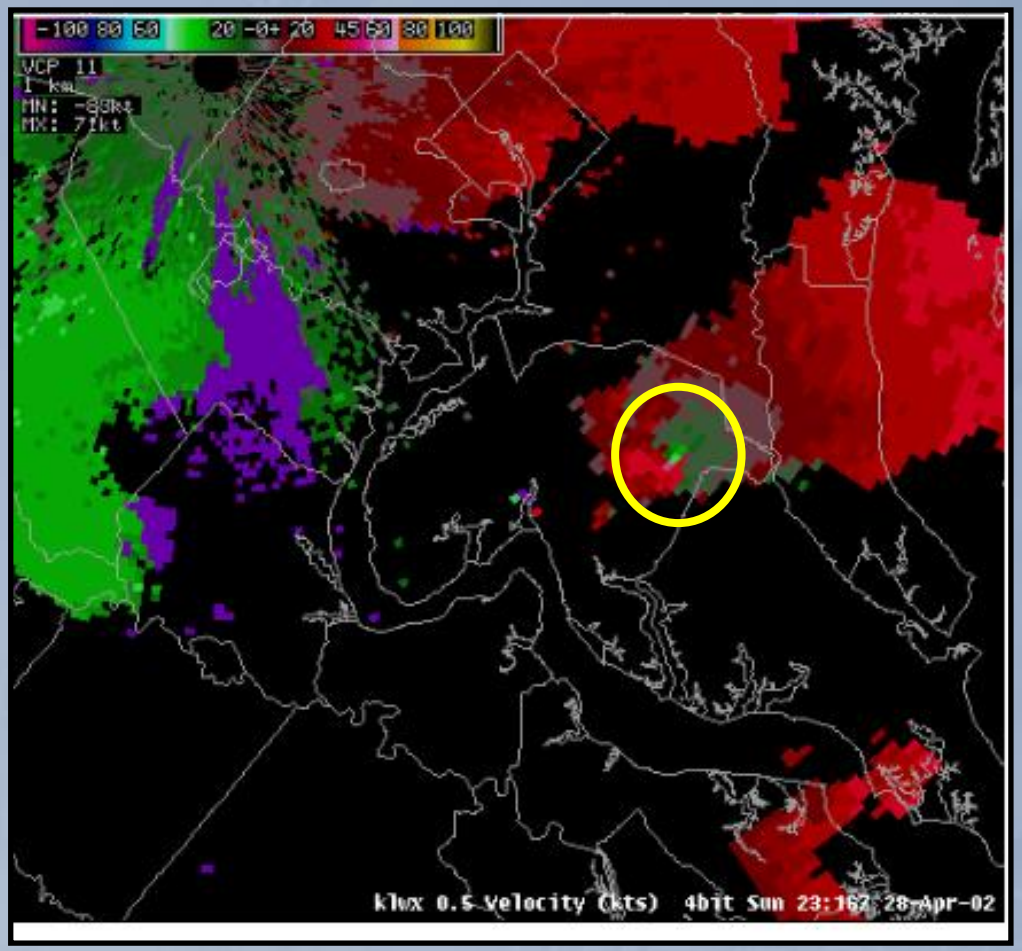
- A radar echo which is linear but bent outward in a bow shape.
- Damaging straight-line winds often occur near the "crest" or center of a bow echo.
- Areas of circulation also can develop at either end of a bow echo, which sometimes can lead to tornado formation - especially in the left (usually northern) end, where the circulation exhibits cyclonic rotation.



Basic Radar

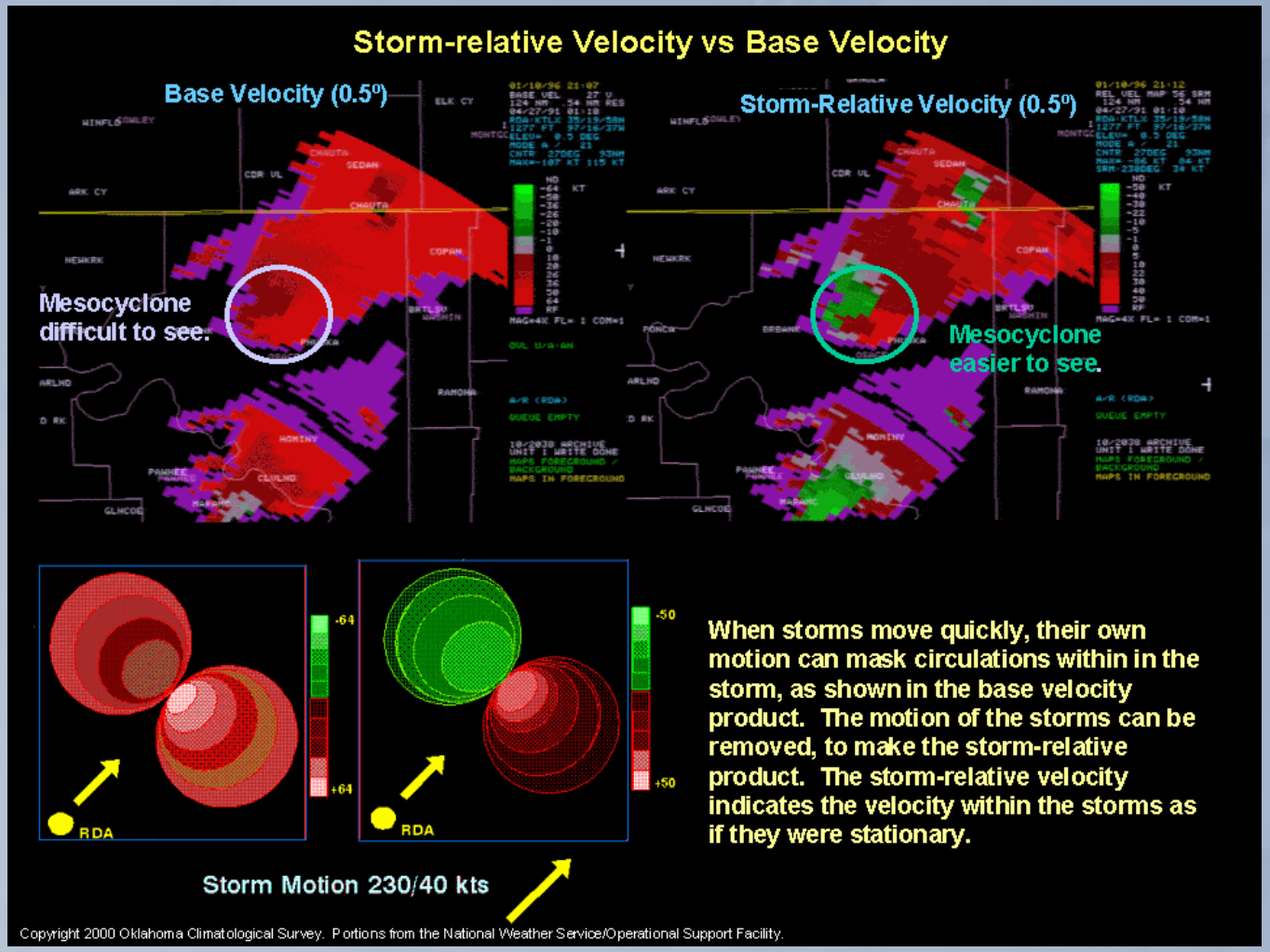
Base Velocity

- Particles moving away from the radar appear red
- Particles moving toward the radar appear green



Basic Radar

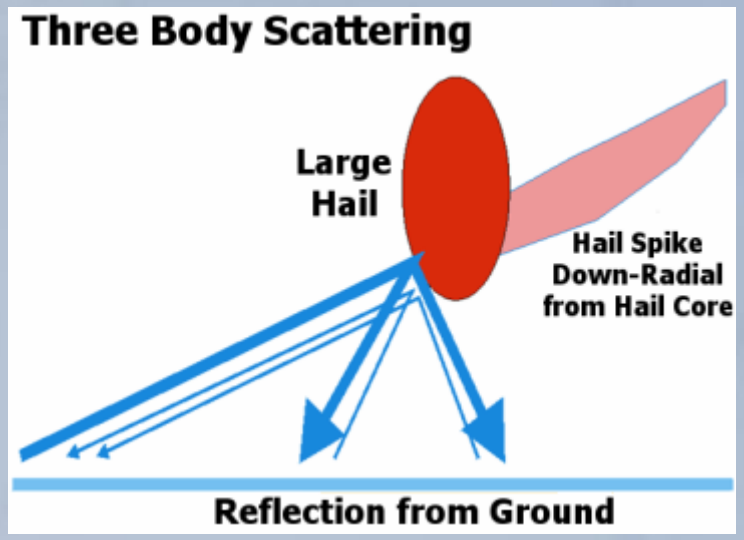
Storm Relative Velocity

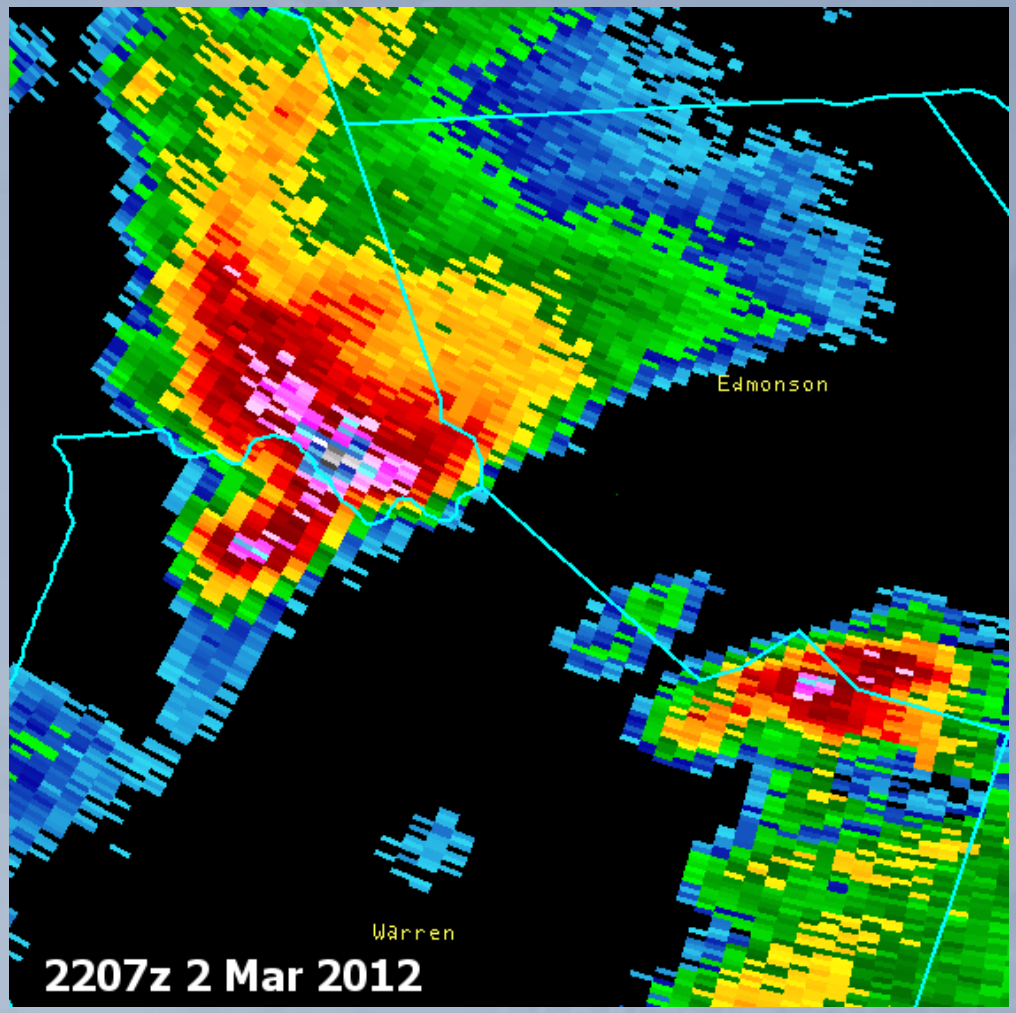


Hail on Radar

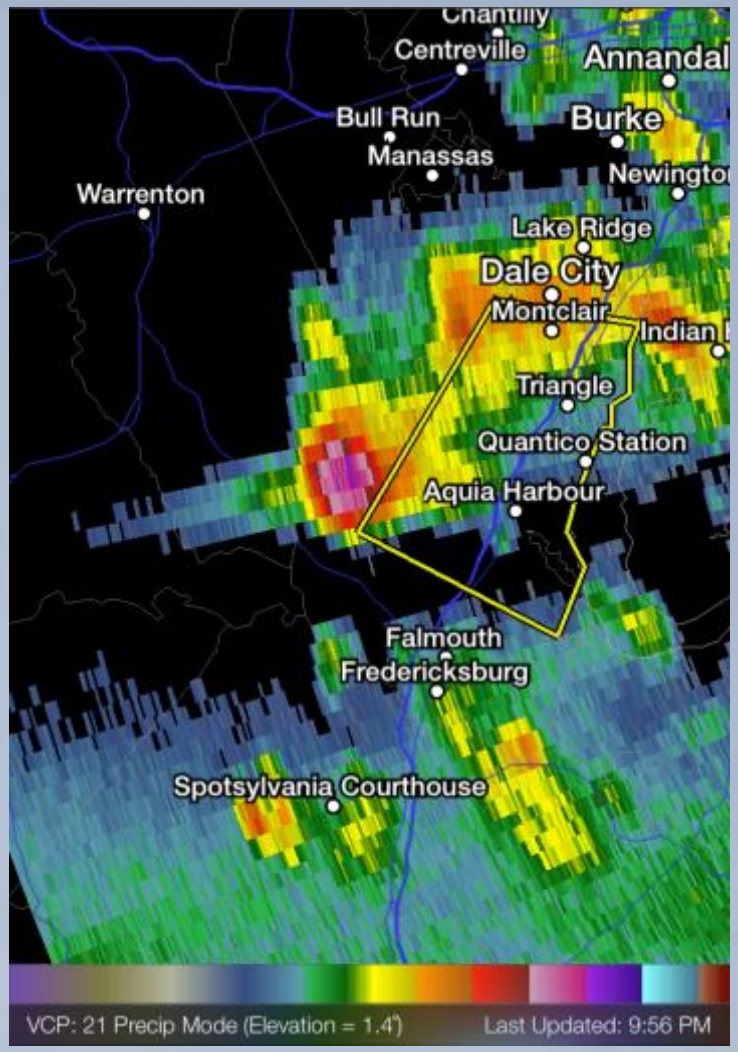
Indicates large hail in storm

Spike appears down-radial or side-radial (side lobe) of hail core

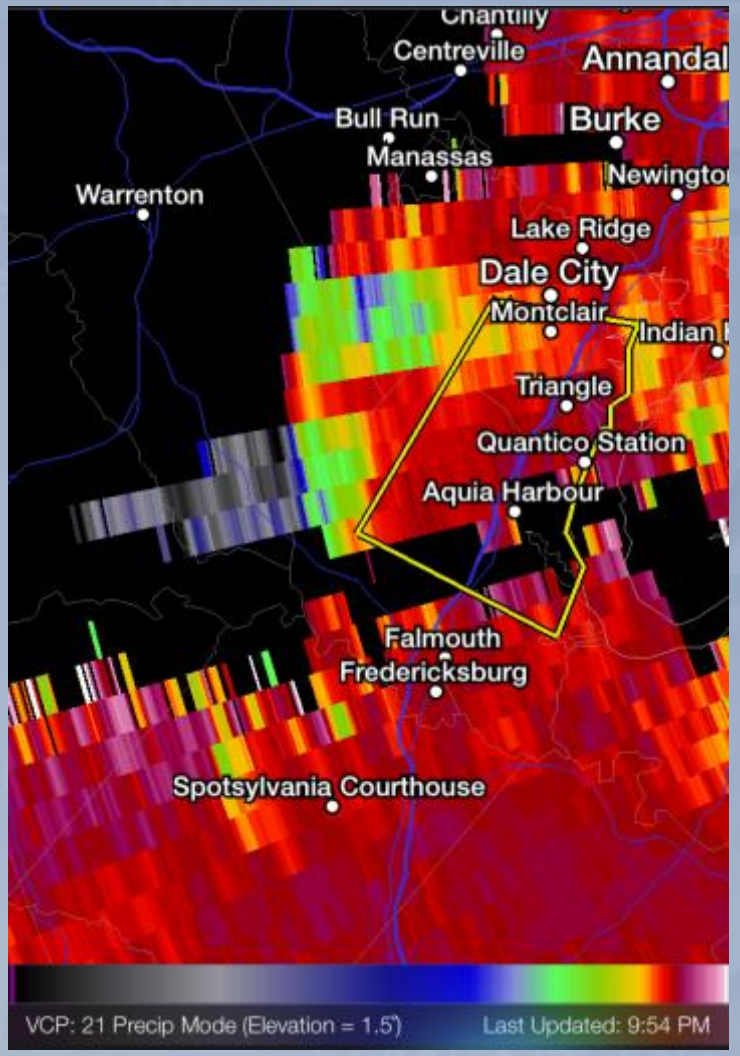




Dual - Polarization

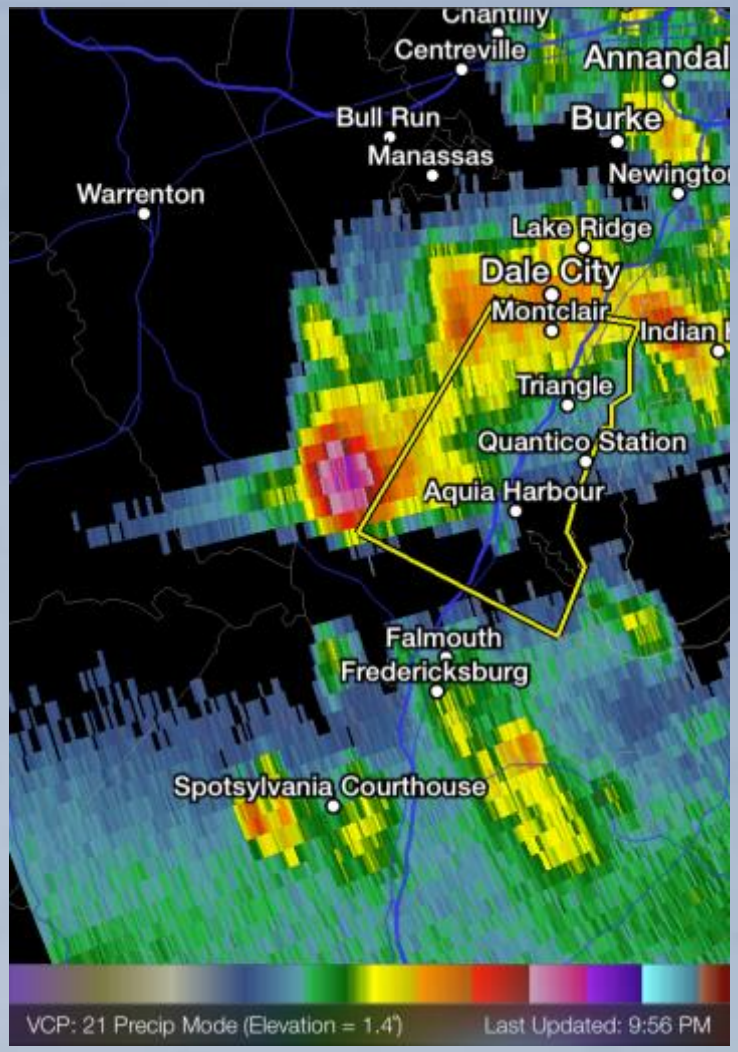


Reflectivity (Z)

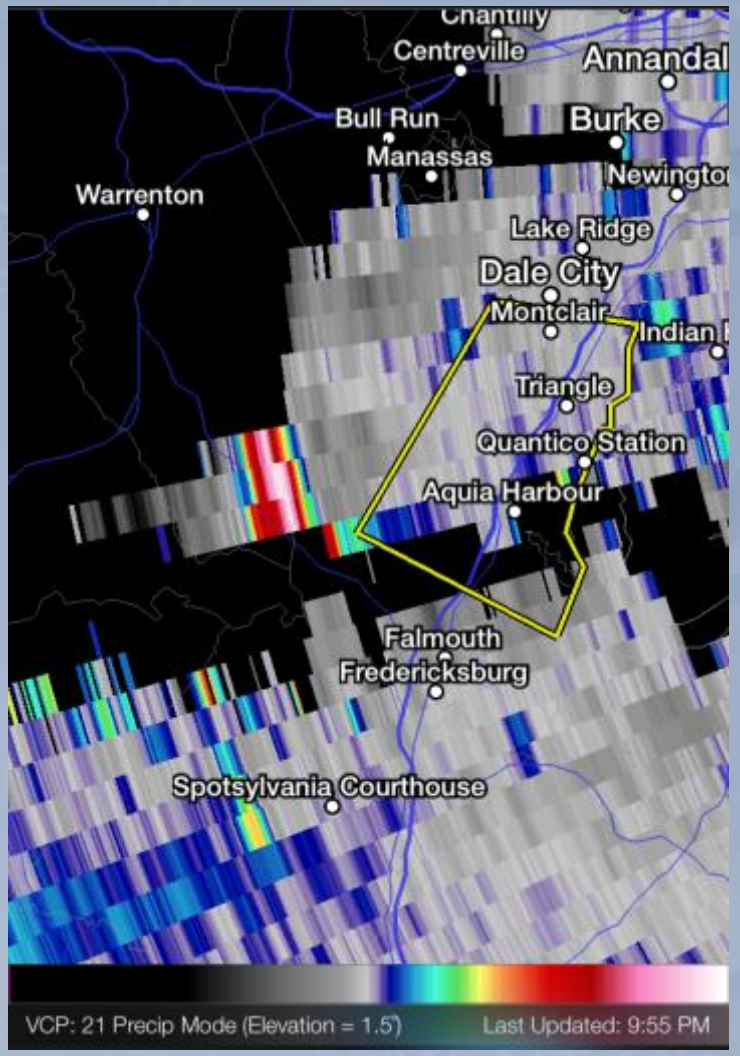


Correlation Coefficient (CC)

Dual - Polarization

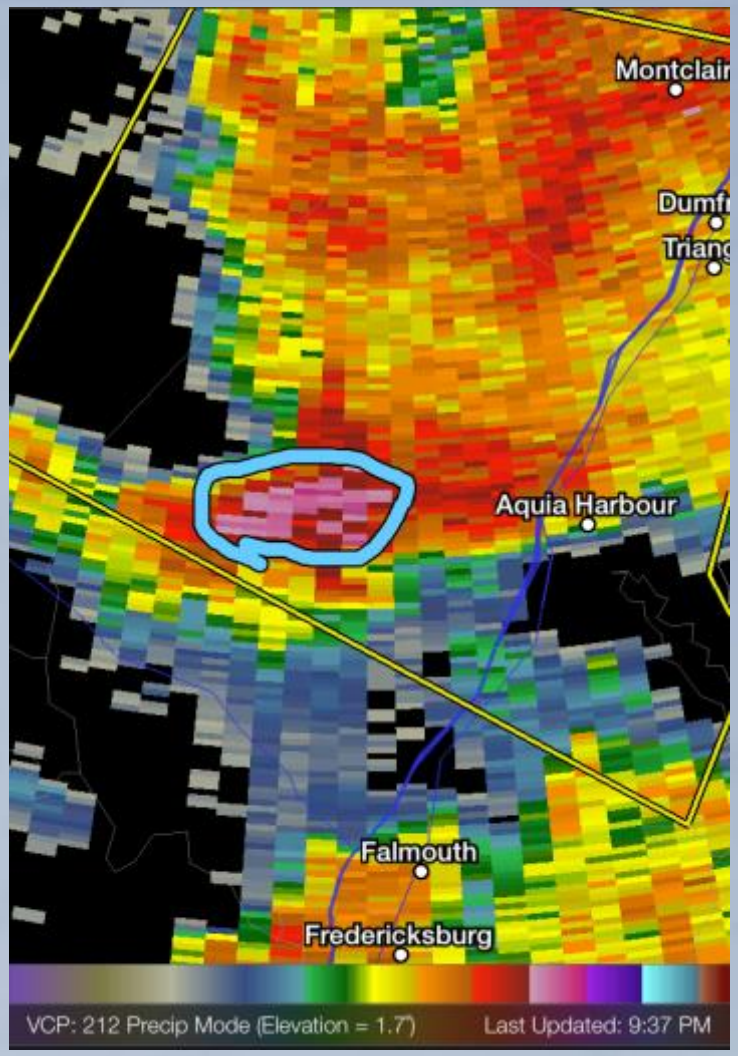


Reflectivity (Z)

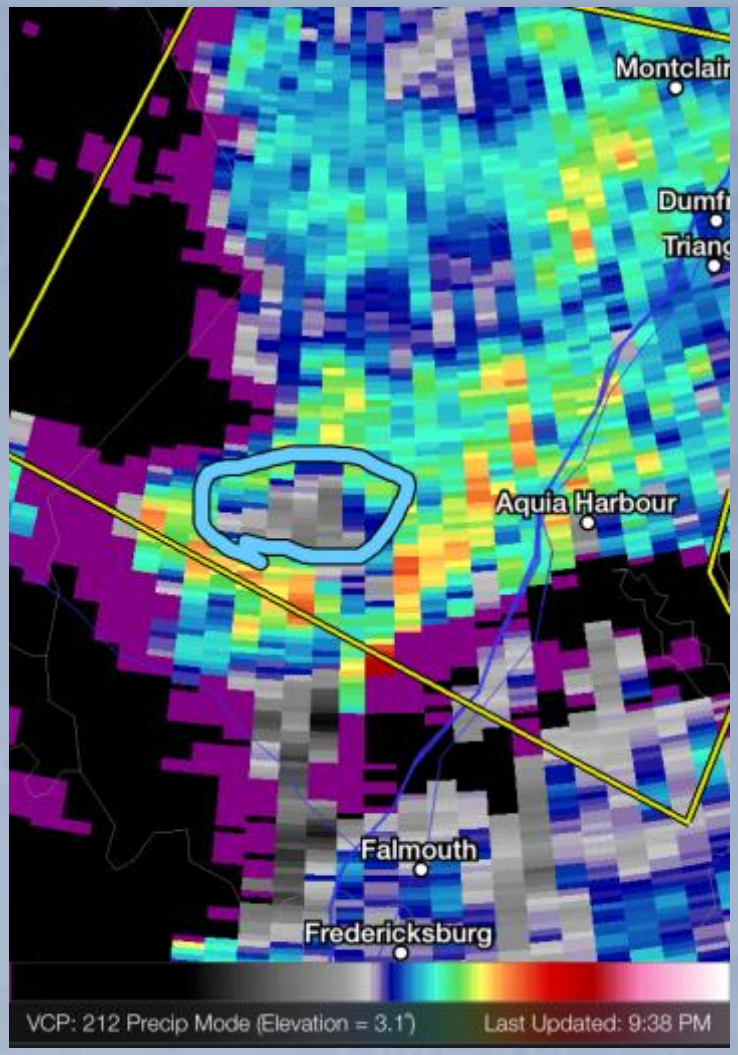


Differential Reflectivity (Z_{DR})

Dual - Polarization

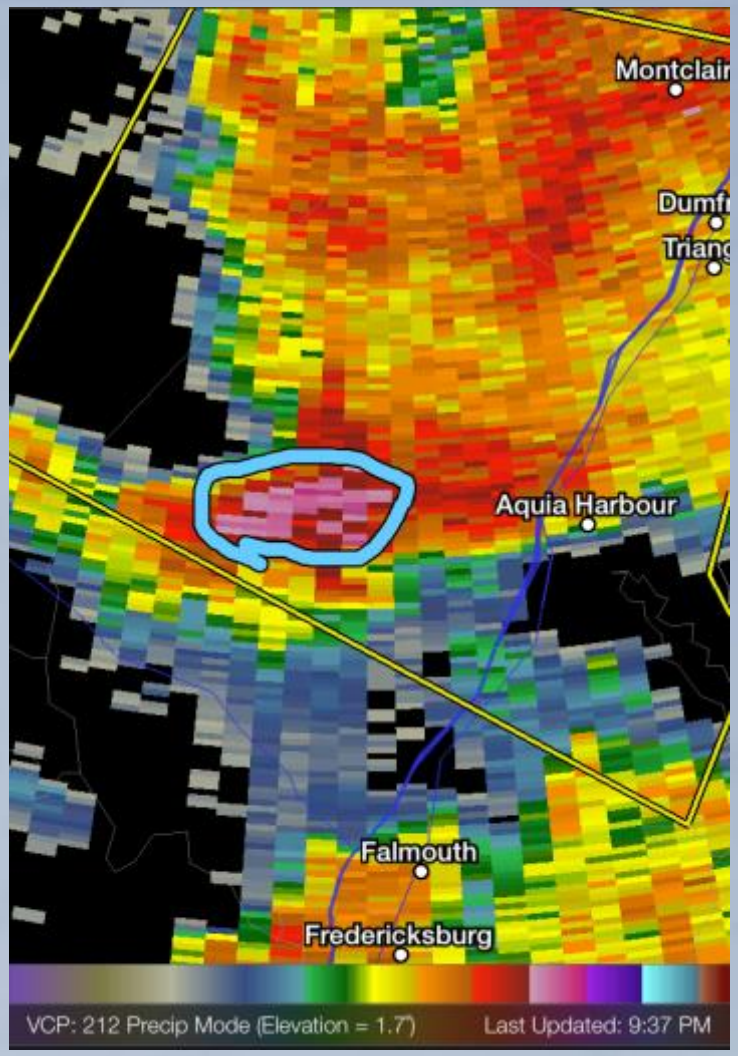


Reflectivity (Z)

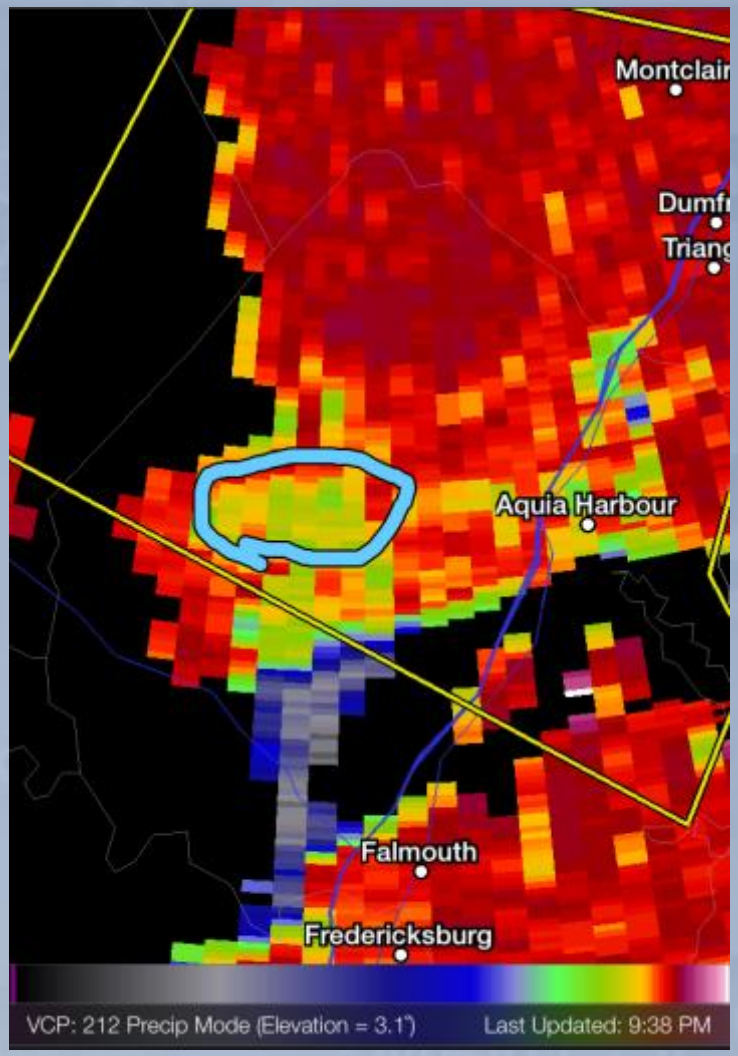


Differential Reflectivity (Z_{DR})

Dual - Polarization

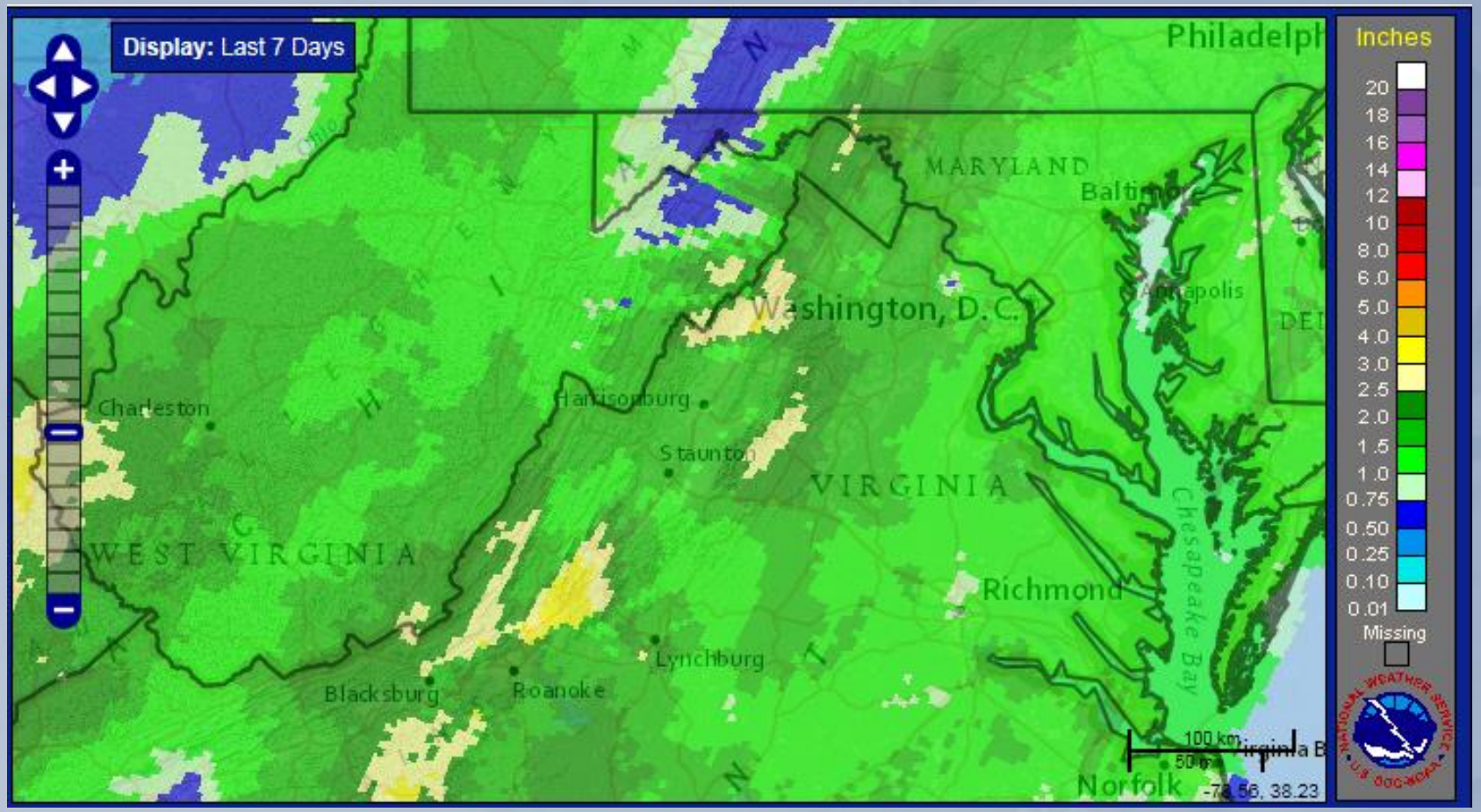


Reflectivity (Z)



Correlation Coefficient (CC)

Precipitation Estimates



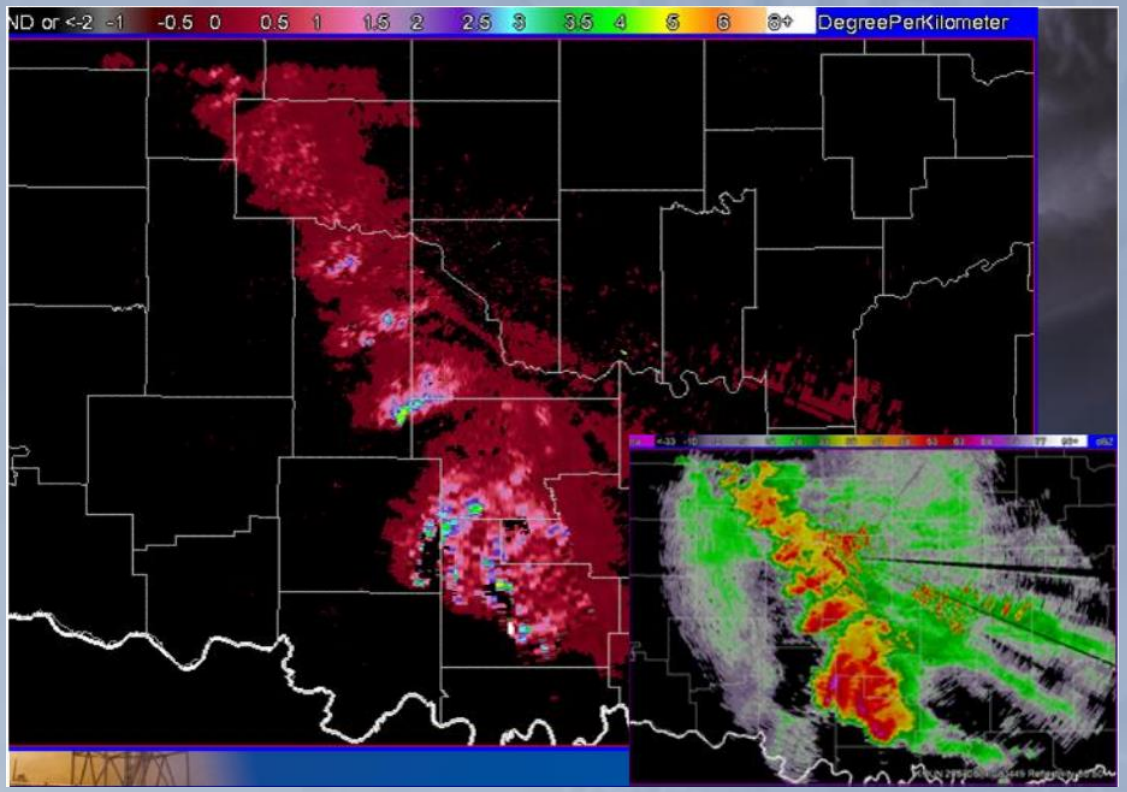
Dual - Polarization

Specific Differential Phase (KDP)

Measures rate of change of horizontally and vertically-polarized phase shift with distance

Improves Precipitation Amount Estimates

- Detects where most liquid water content is (higher values)
- Snow gives low values of KDP
- Removes effect of hail contamination

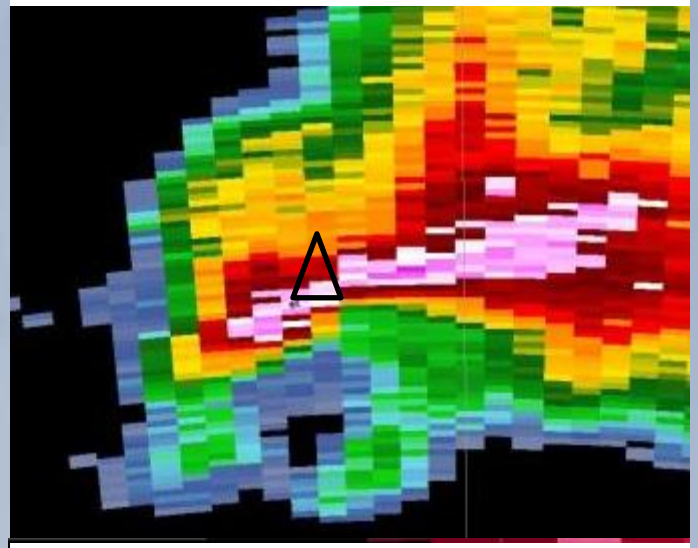


Z ~ 65, ZDR ~ -.5, CC ~ .94, KDP ~ 2

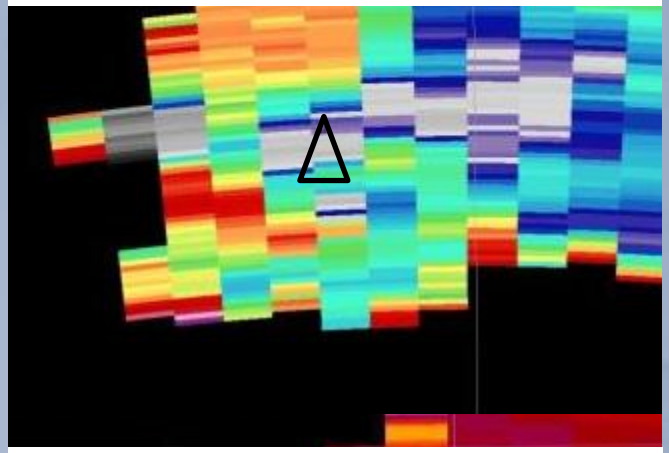
Hail & rain

Z high - hail possible

Z



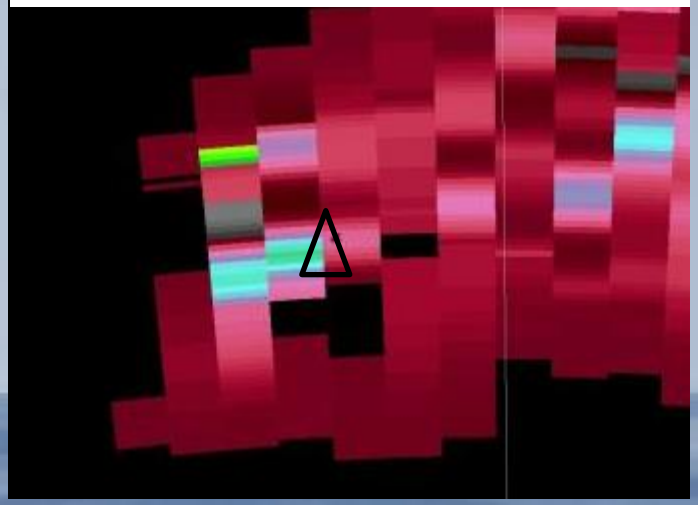
ZDR Near 0 - many spherical particles



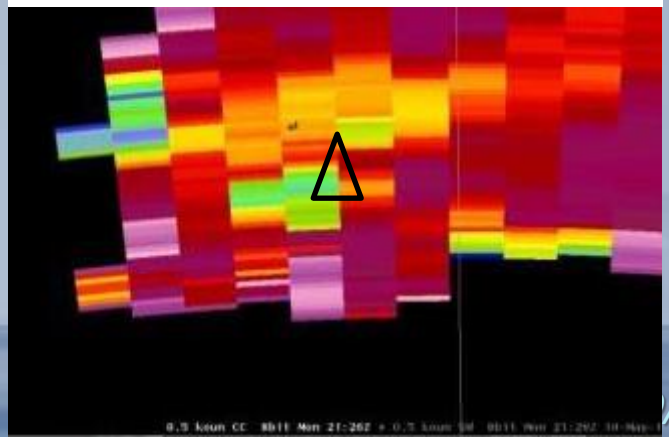
ZDR

KDP high - some liquid

KDP



CC depressed - likely mixed precip



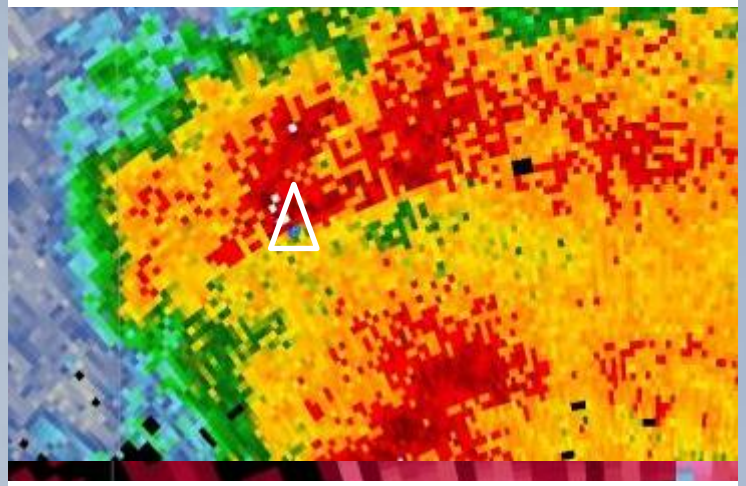
CC

Z ~ 61, ZDR ~ 3.7, CC ~ .95, KDP ~ 3.0 What is it?

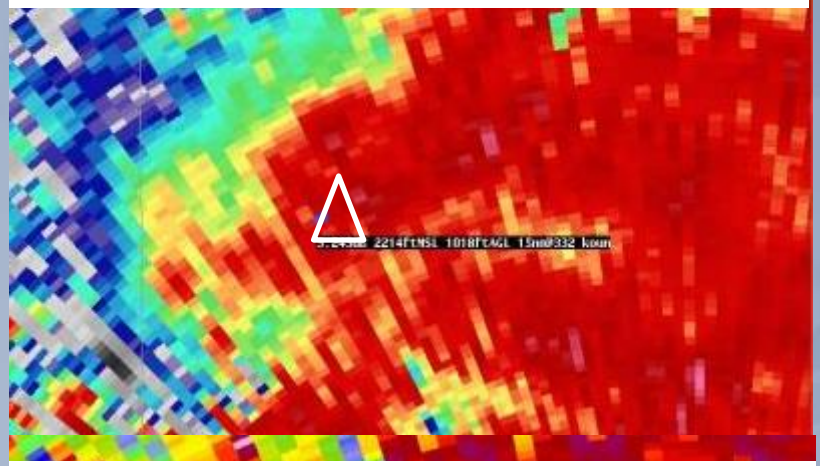
Heavy rain, little mix

Z

Z high - rain/hail

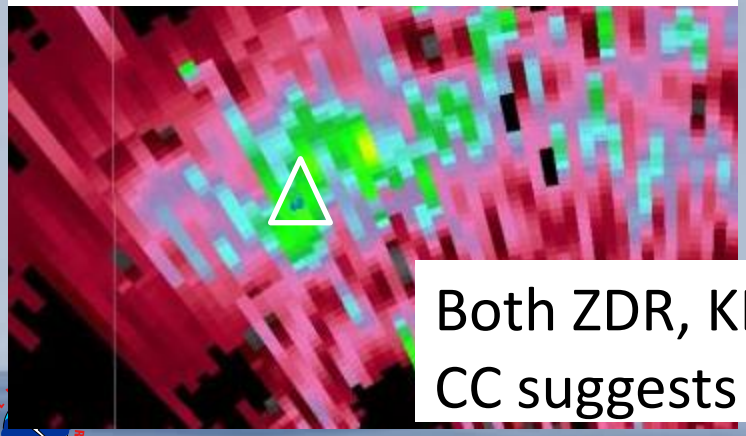


ZDR high - big raindrops



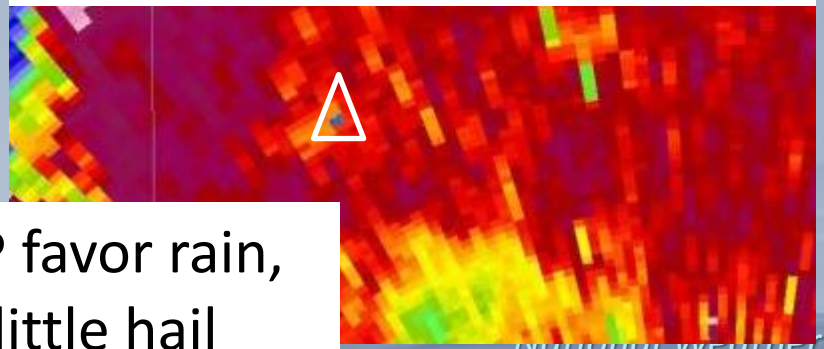
ZDR

KDP high - Lots of liquid



KDP

CC slightly depressed - suggests mix



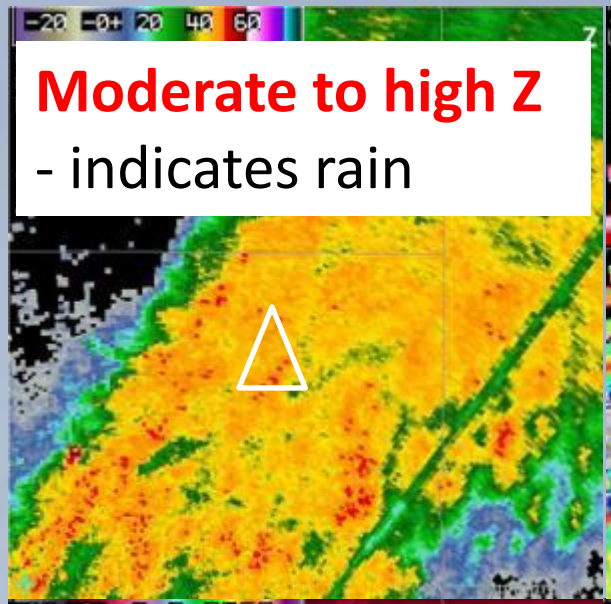
CC

Both ZDR, KDP favor rain, CC suggests a little hail

Z ~ 48, ZDR ~ 1.8, CC ~ .99, KDP ~ 1.8 What is it?

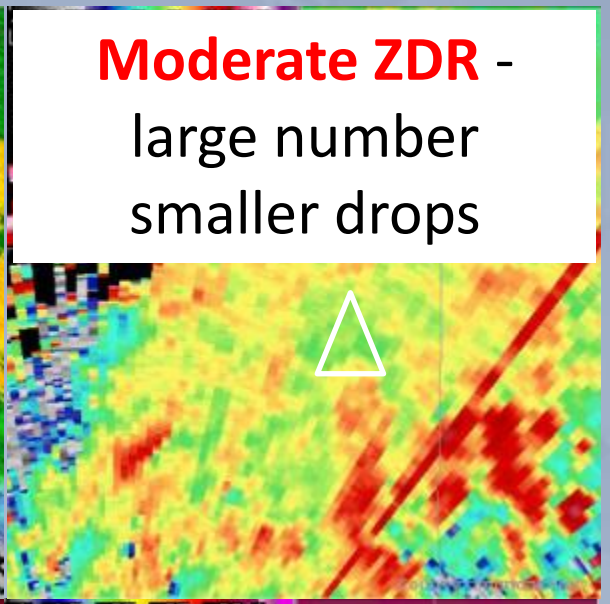
Tropical, heavy rain

Z



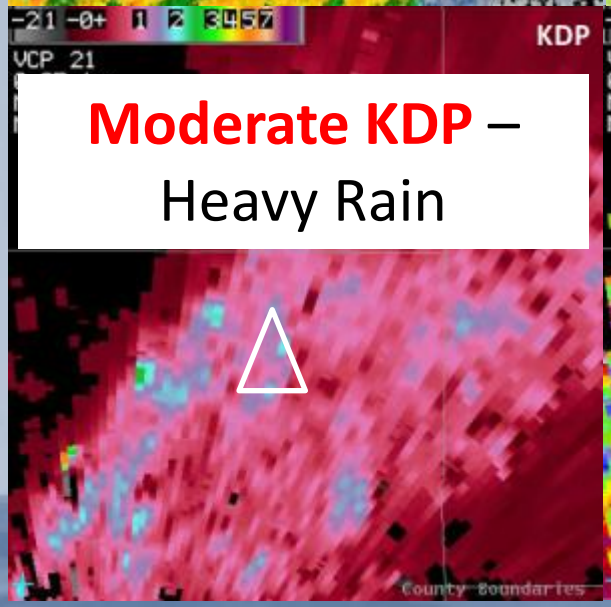
Moderate to high Z - indicates rain

ZDR



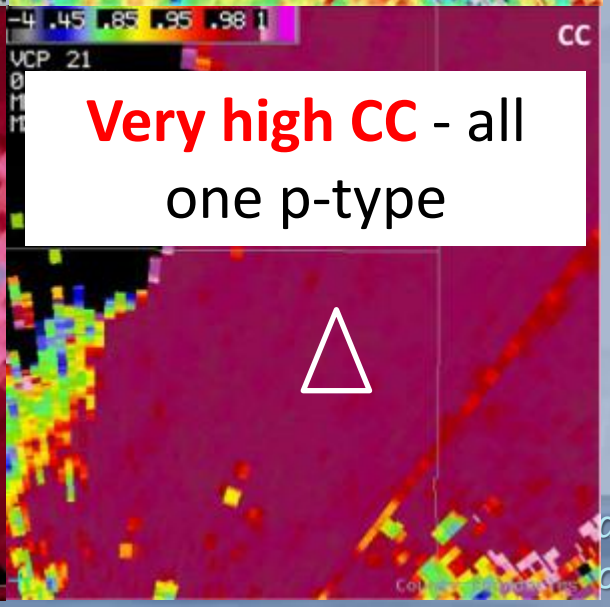
Moderate ZDR - large number smaller drops

KDP

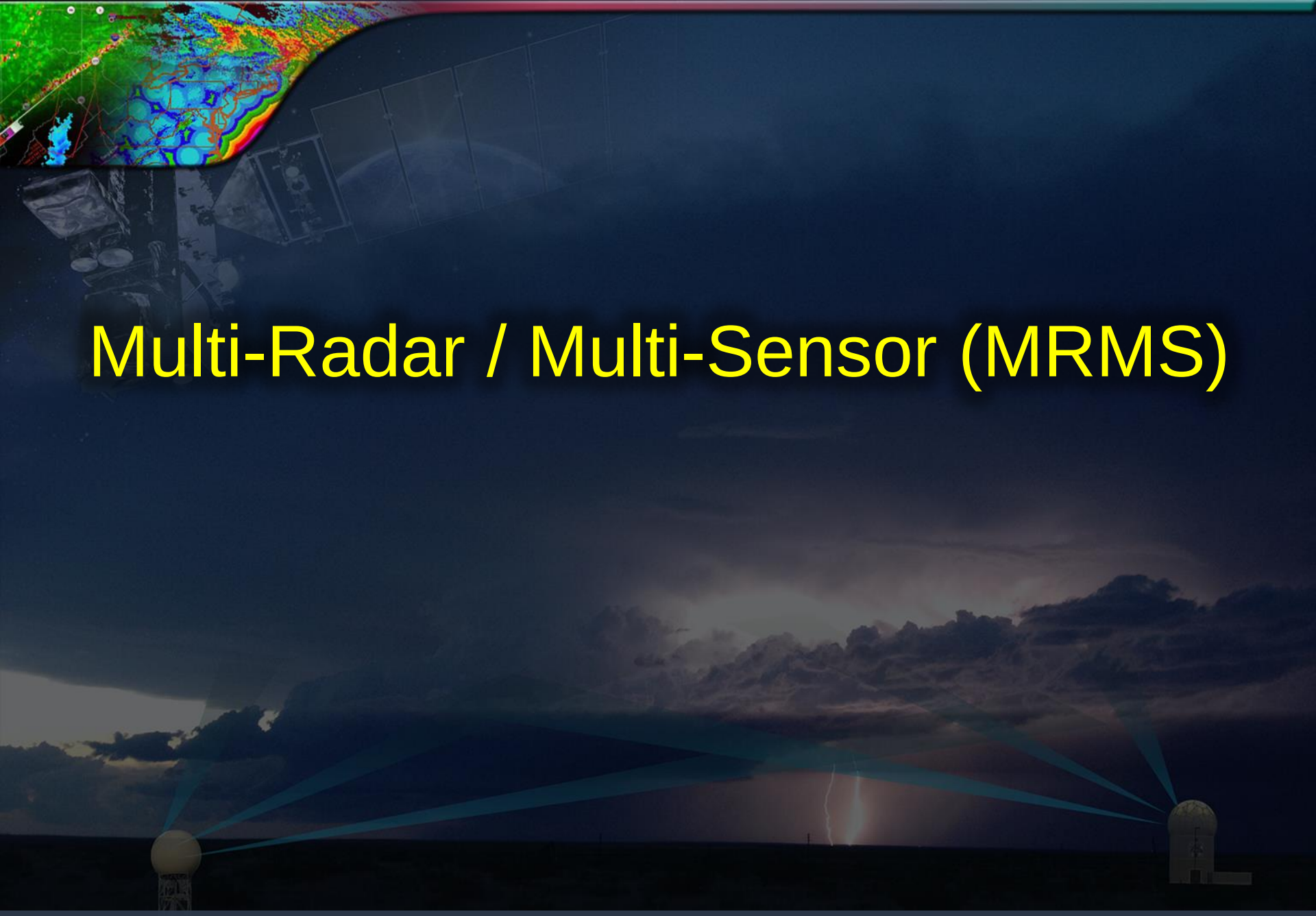


Moderate KDP – Heavy Rain

CC

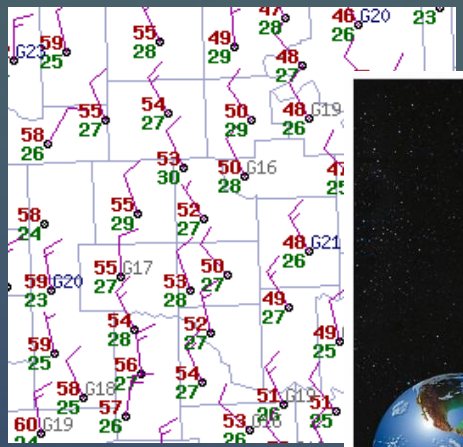


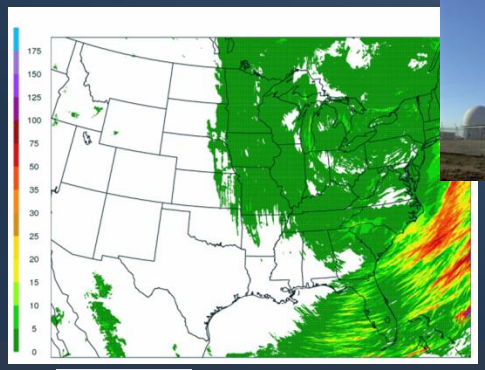
Very high CC - all one p-type



Multi-Radar / Multi-Sensor (MRMS)

Multiple sensors





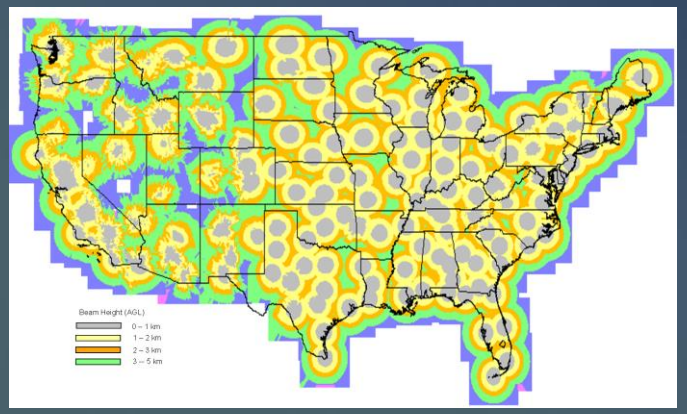
MRMS

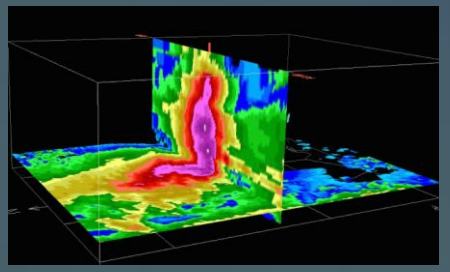
Multiple-Radar 3D Reflectivity Mosaic

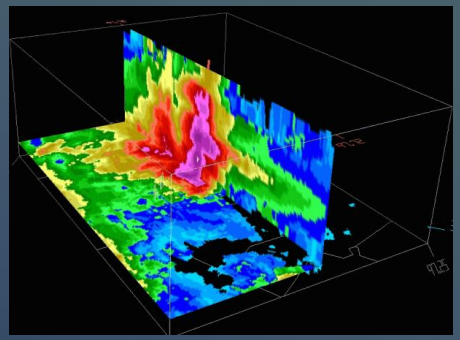
Exploits multiple-radar coverage to mitigate single-radar limitations

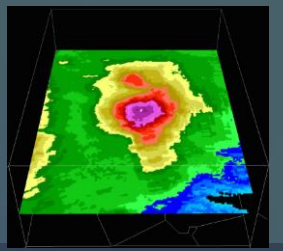
Seamless high-res 3D cubes of radar data covering CONUS:

- Reflectivity (1 km)
- Azimuthal Shear (500 m)



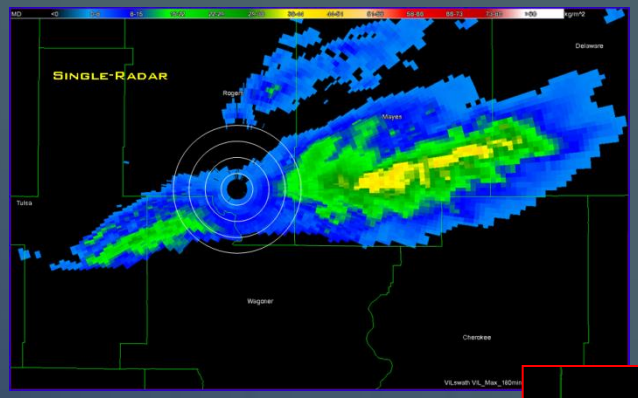


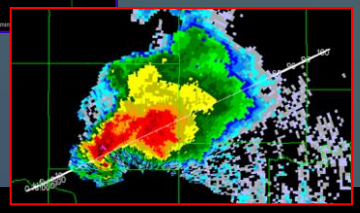




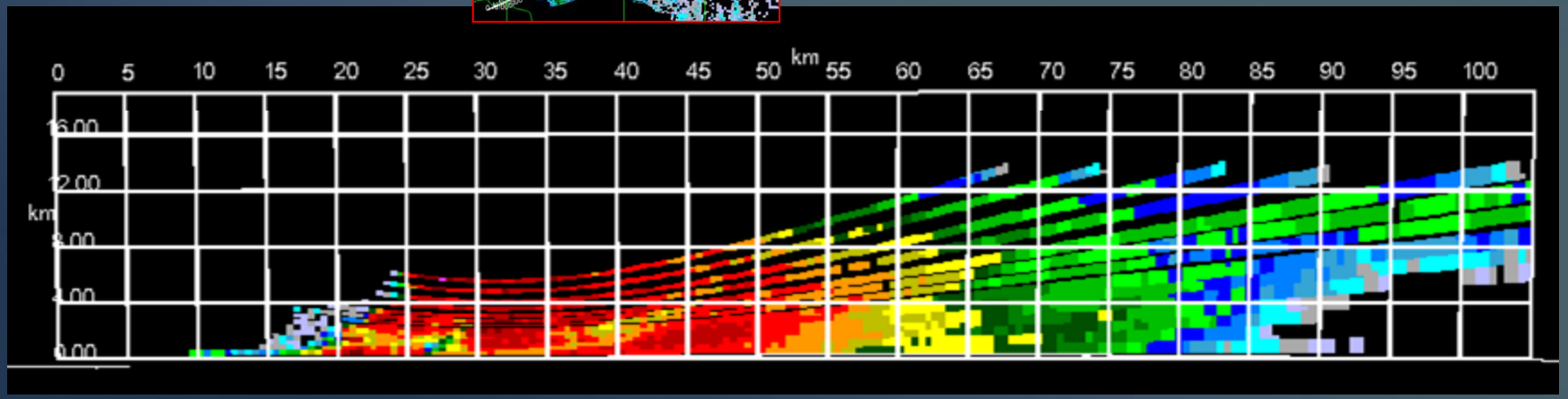
MRMS

Single radar data



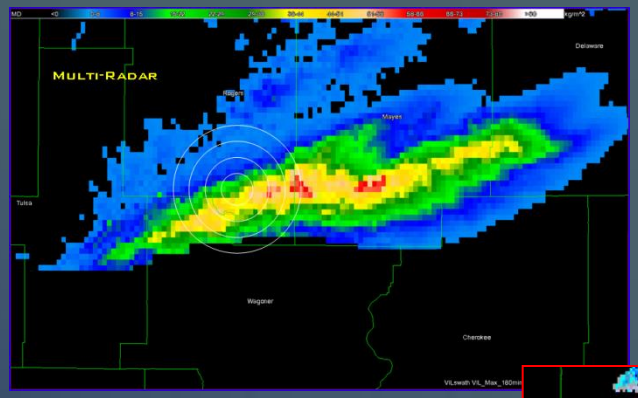


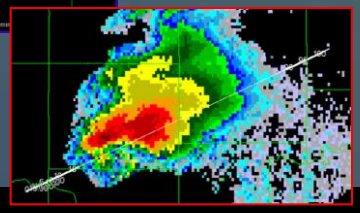
Single Radar



MRMS

Blended 3D multi-radar data

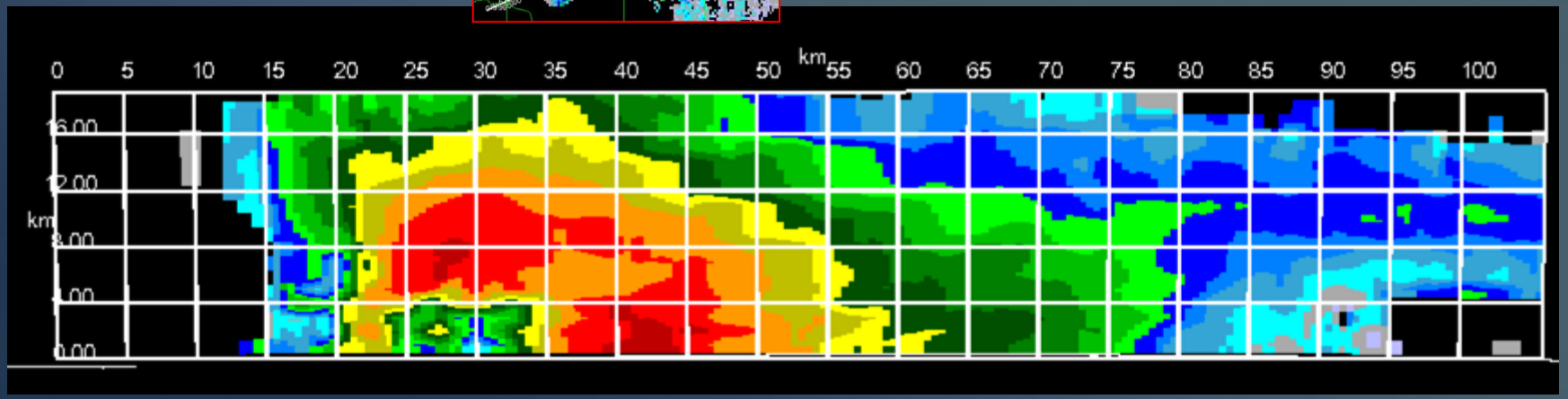




Multiple Radars

Radars in network supplement each other:

- Overlapping coverage
- Fills in gaps from cones-of-silence and terrain blockage
- Increased sampling frequency

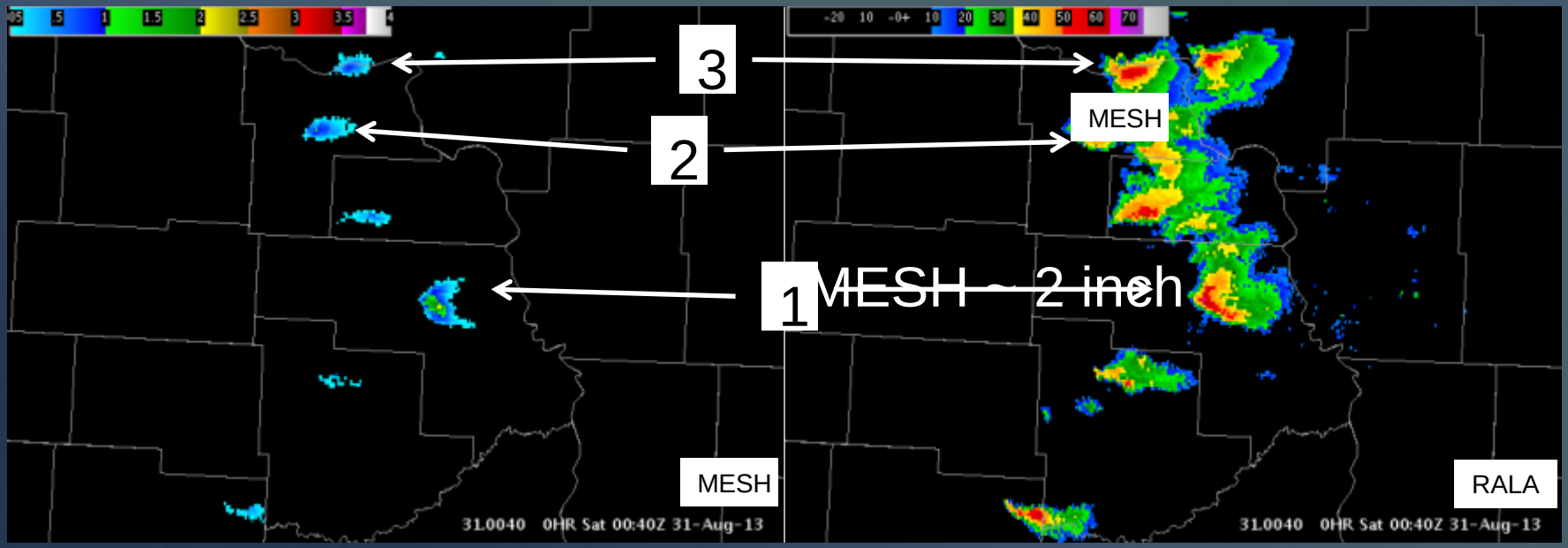


MRMS

Max Est Size of Hail (MESH) Applications

- Useful for assessing:
  - 2-D distribution of hail
  - Largest hailstone size

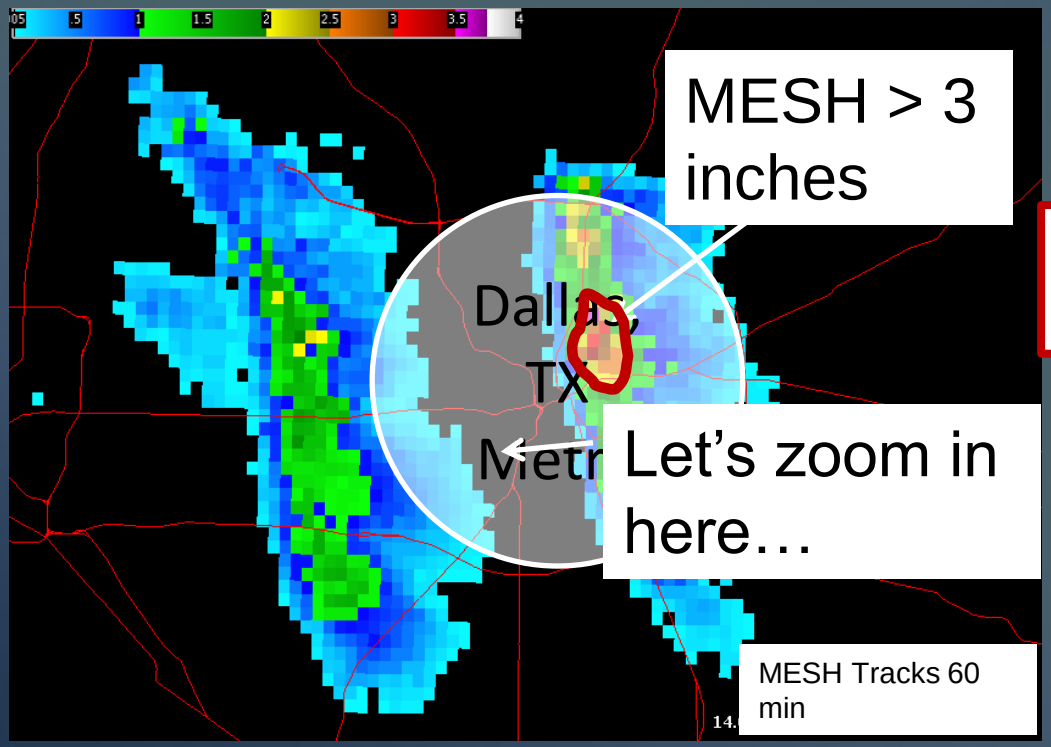
Rank the storms by hail potential…



MRMS

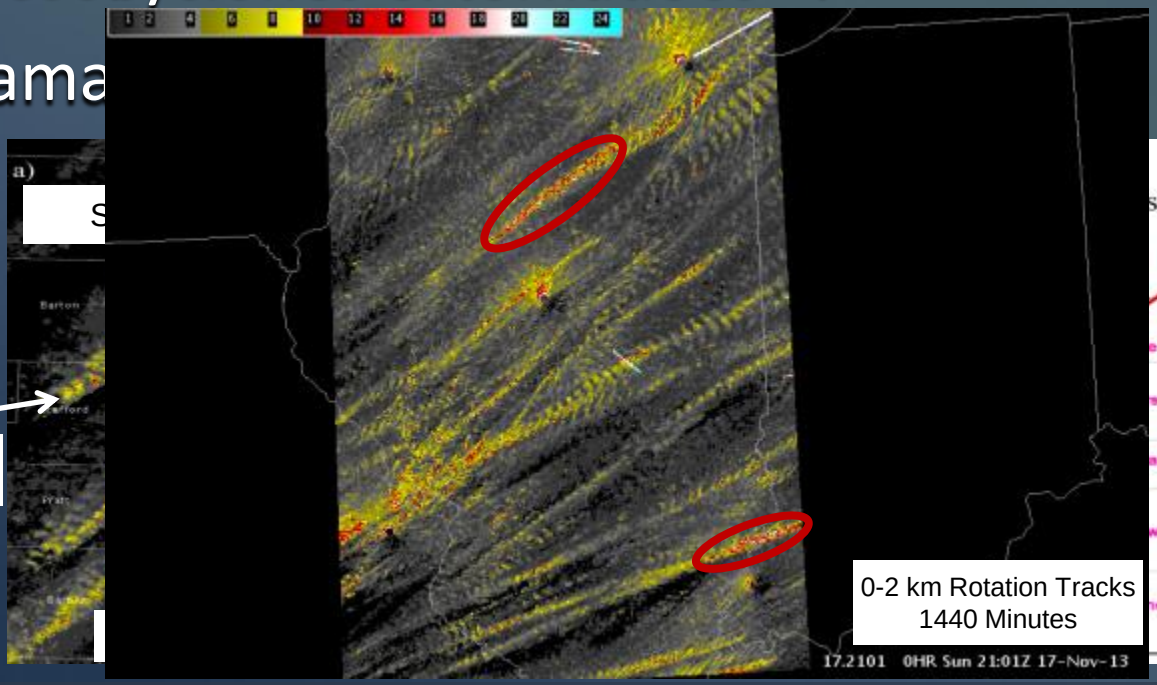
MESH Tracks Applications

- Determining locations of largest hail fall for
  - Verification & emergency response



Rotation Tracks Applications

- 0-2 km Rotation Tracks & spatial coverage of circulations with:
  - Useful directing first responders & damage surveyors to areas affected by tornadoes
  - Mesocyclones & tornadoes
  - Dama



Intensifying

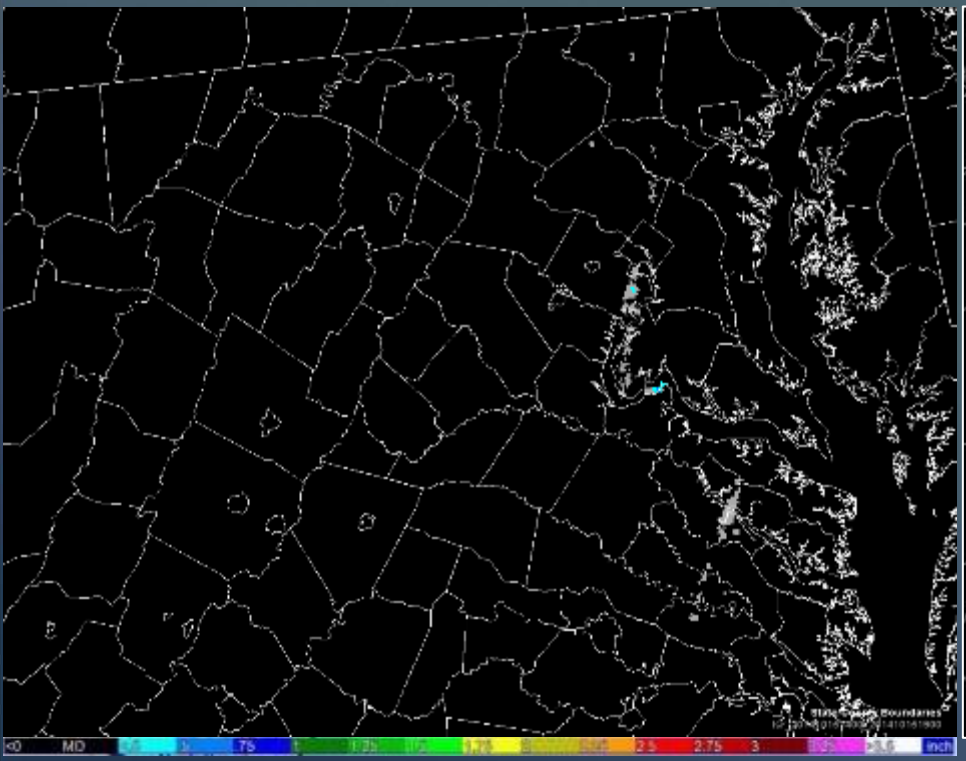
Damage and/or injuries likely!

Local Contributing Radars

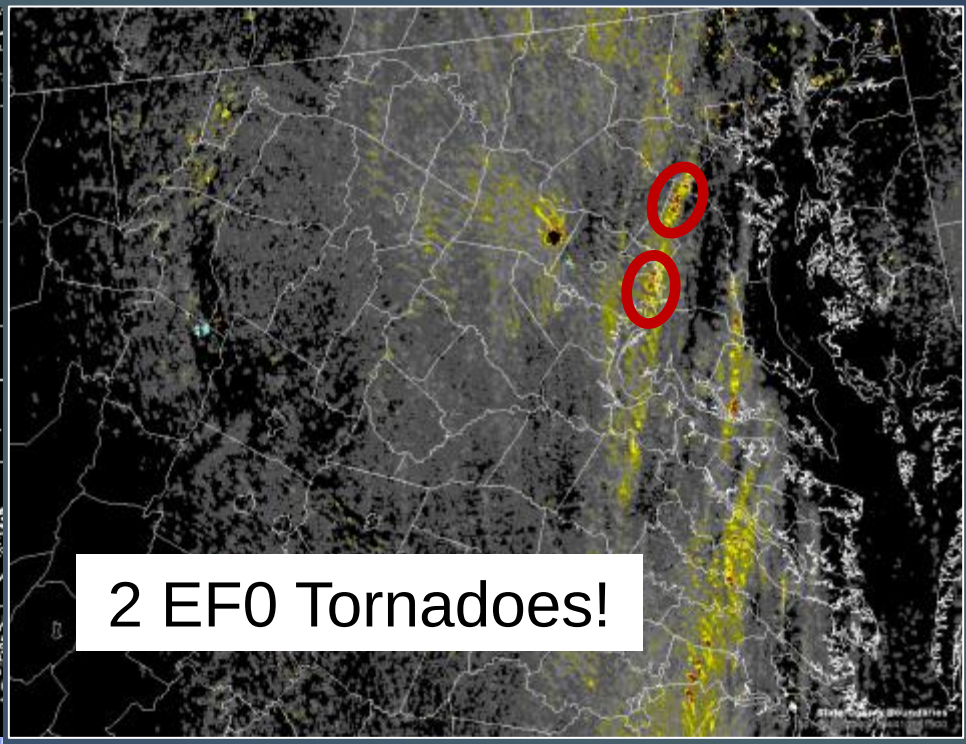
MRMS

Local Examples

MESH Tracks



Rotation Tracks

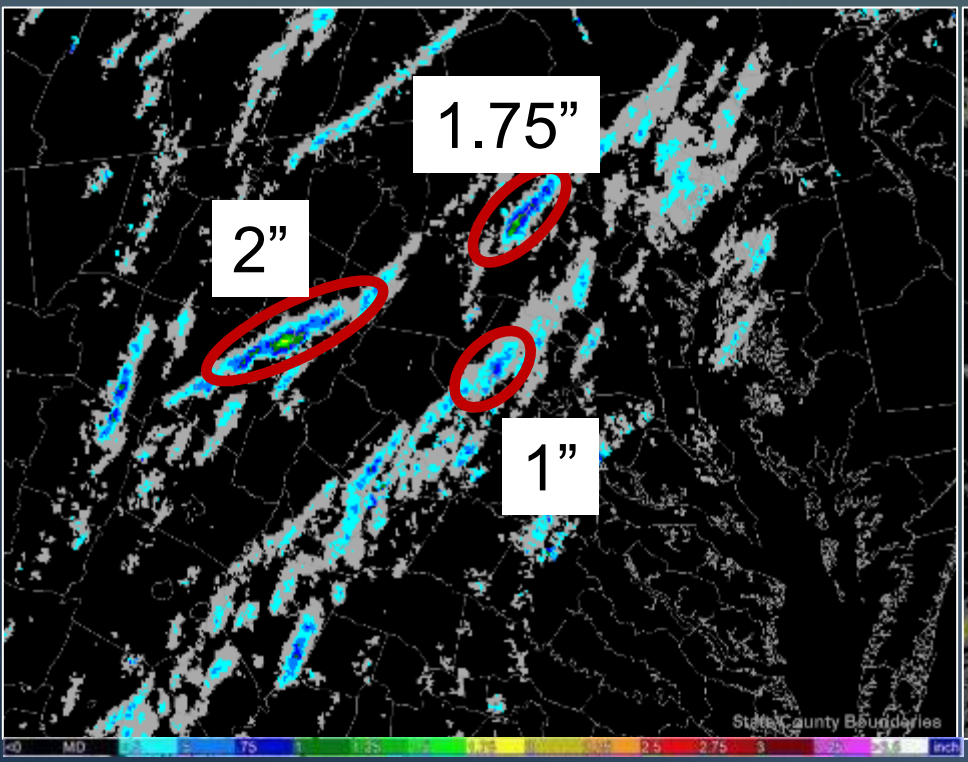


15 Oct 2014: Tornadoes & Damaging Wind

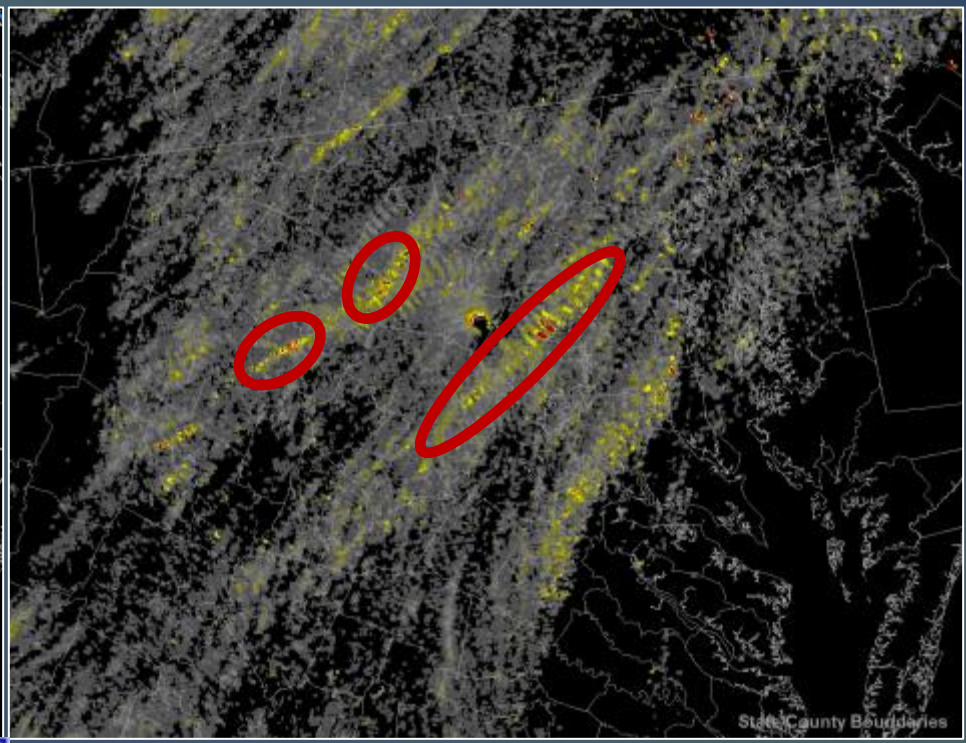
MRMS

Local Examples

MESH Tracks



Rotation Tracks

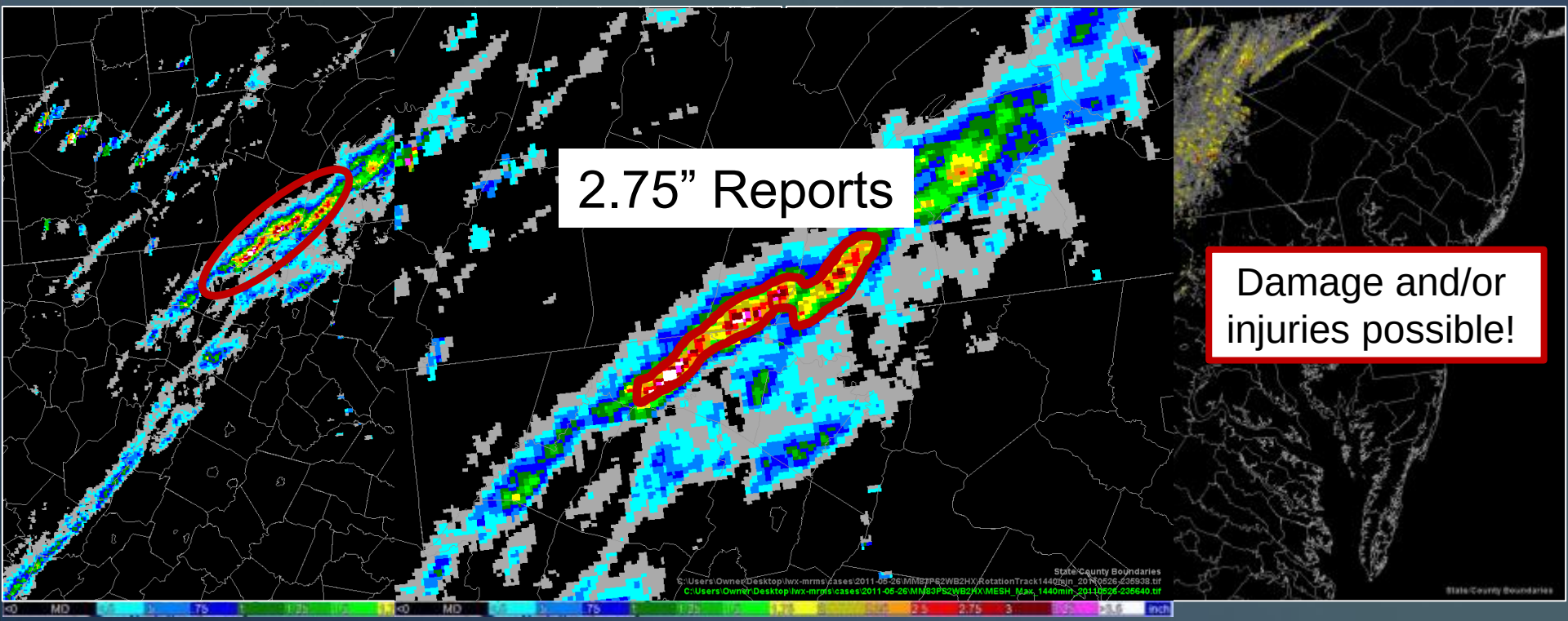


3 July 2014: Hail & Damaging Wind

MRMS

Local Examples

MESH Tracks | MESH Tracks Rotation Tracks



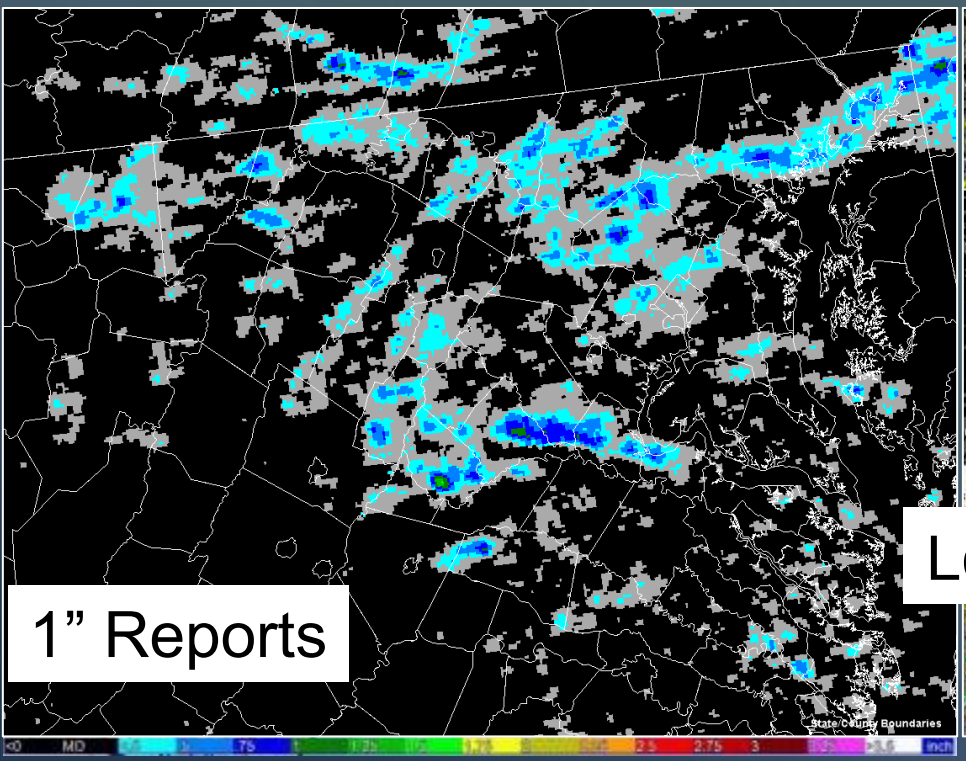
26 May 2011: Damaging Hail

MRMS

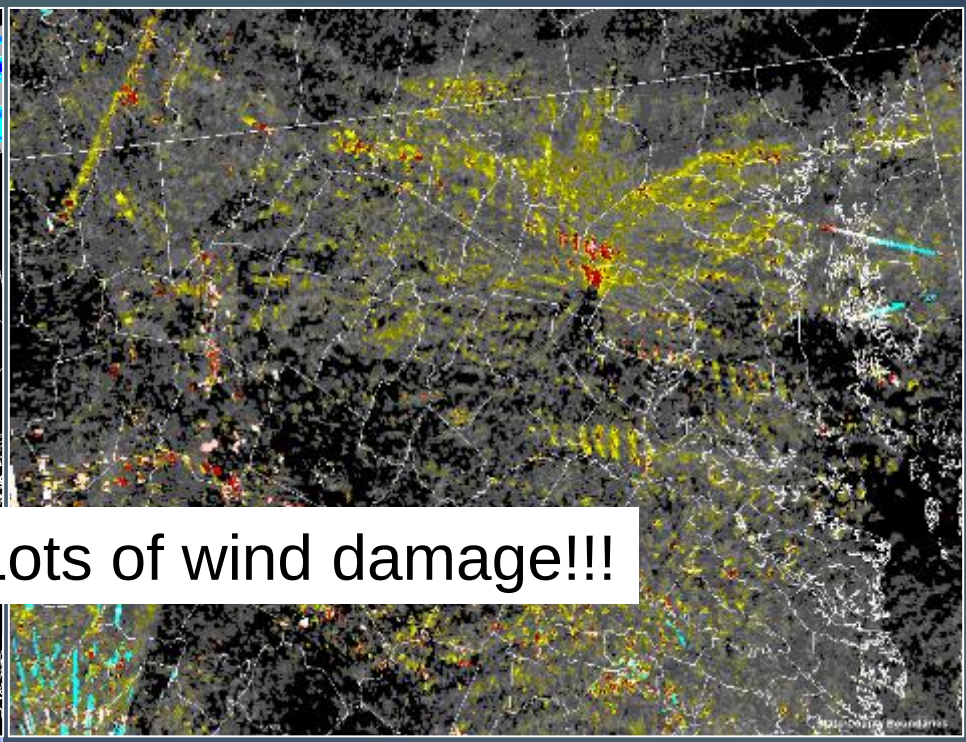
Local Examples

MESH Tracks

Rotation Tracks



1” Reports

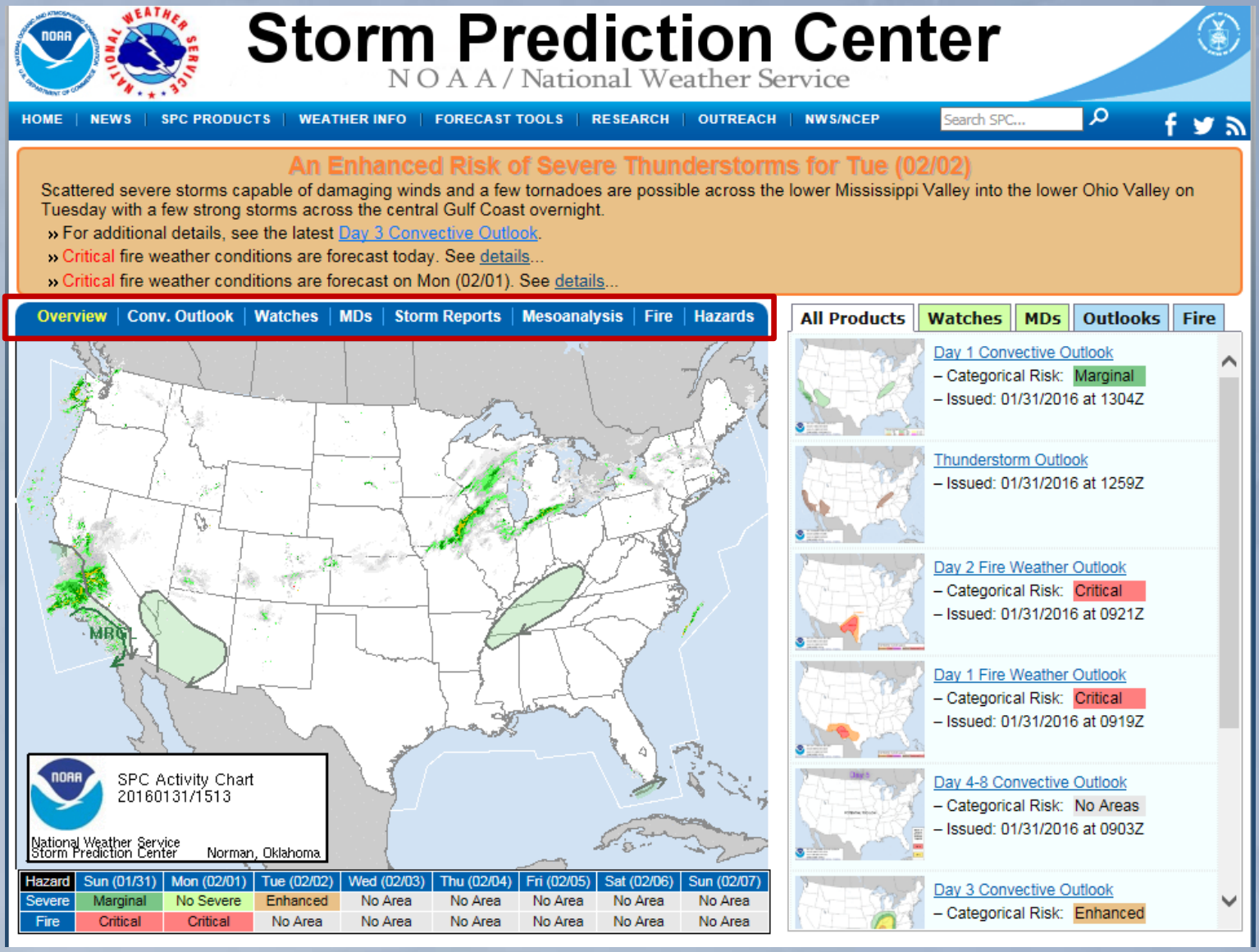


Lots of wind damage!!!

30 June 2012: Derecho

MRMS

SPC Products and Tools



Hazard	Sun (01/31)	Mon (02/01)	Tue (02/02)	Wed (02/03)	Thu (02/04)	Fri (02/05)	Sat (02/06)	Sun (02/07)
Severe	Marginal	No Severe	Enhanced	No Area	No Area	No Area	No Area	No Area
Fire	Critical	Critical	No Area	No Area	No Area	No Area	No Area	No Area

SPC Outlooks

Have split the previous Slight Risk category into two new: Slight & Enhanced

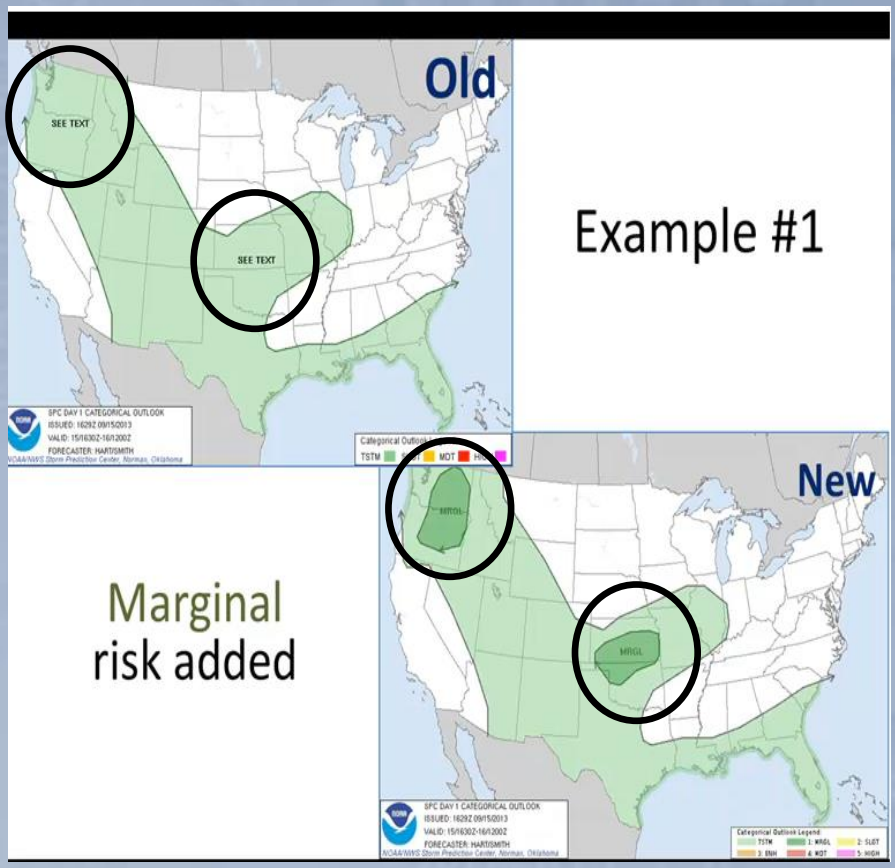
Day 1, Day 2, Day 3 Categorical Outlook Changes
effective October 22, 2014

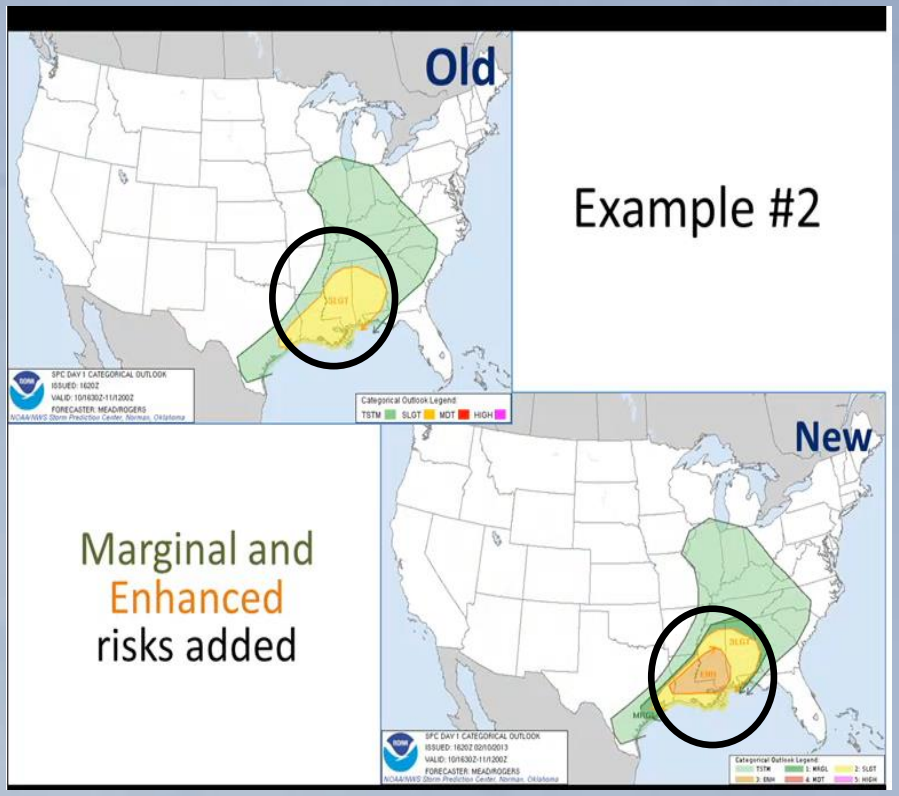
*Increase risk categories to **5 levels** for Day 1 and Day 2 Outlooks*
*Increase risk categories to **4 levels for** Day 3 Outlook (High not forecast)*

"See Text"	→	Marginal Line/area added to Categorical Outlook
Slight	→	Slight
	→	Enhanced (Slight)
Moderate	→	Moderate Essentially unchanged but SIG severe required
High	→	High

****General thunder will still be noted****

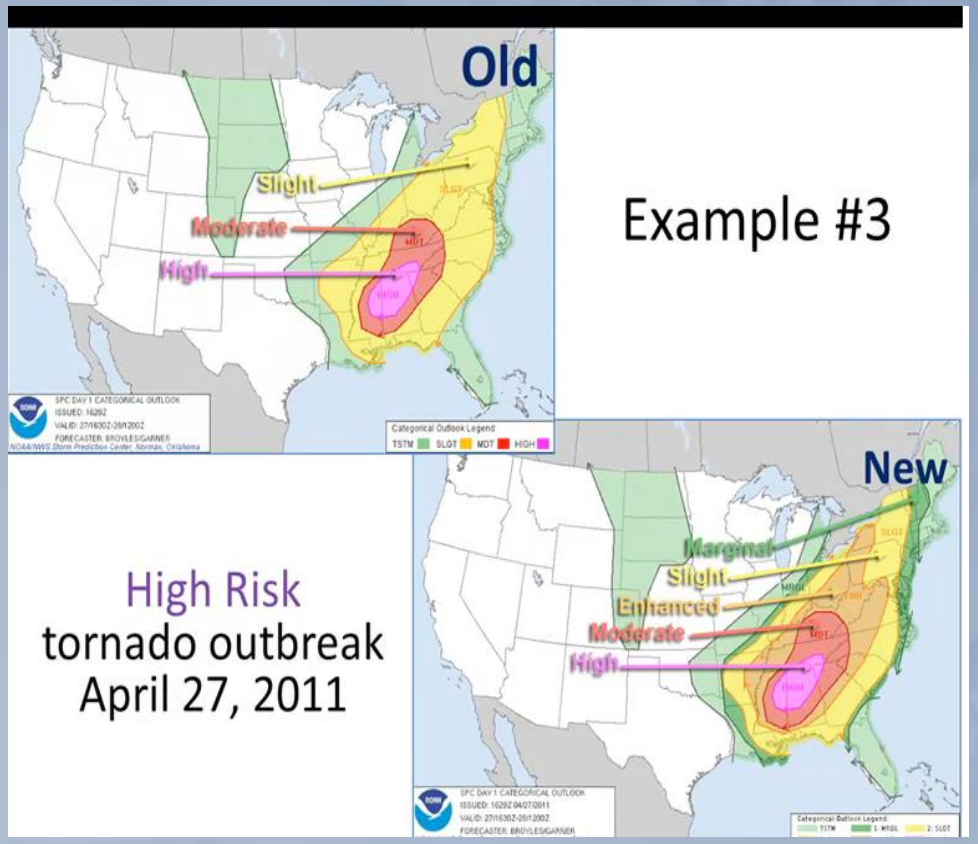
Examples



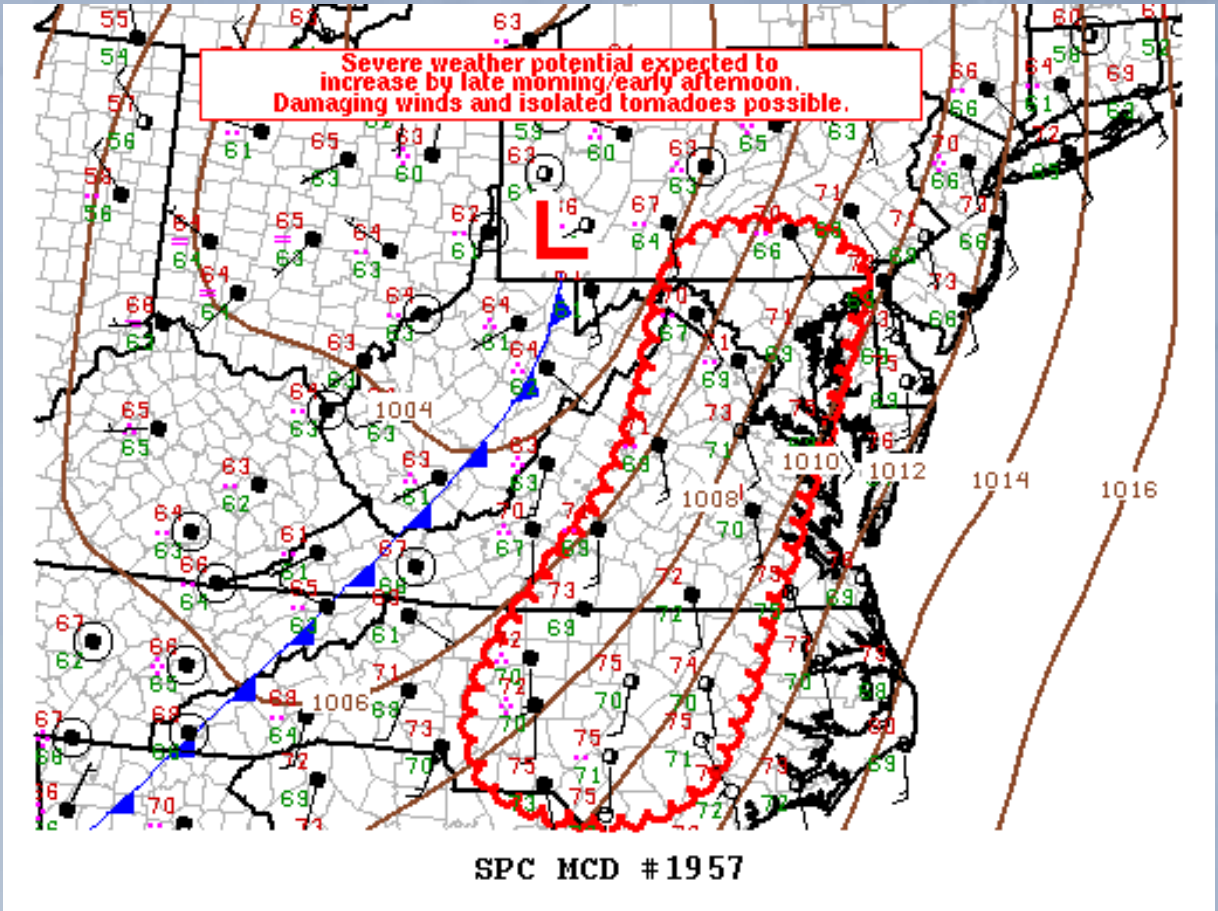


Categorical Outlook Legend:

TSTM	1: MRGL	2: SLGT
3: ENH	4: MDT	5: HIGH

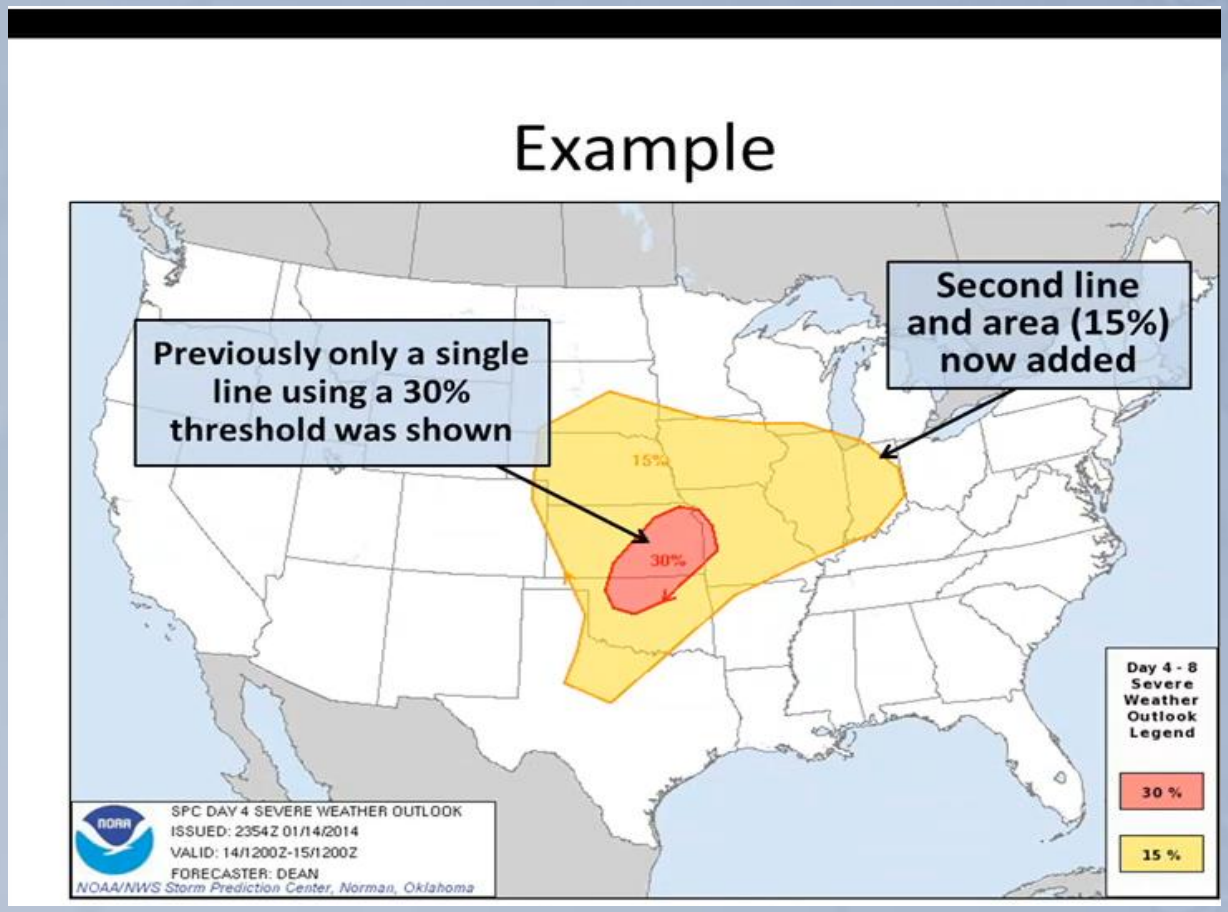


SPC Outlooks



SEVERE THUNDERSTORM POTENTIAL…INCLUDING DAMAGING WINDS AND A FEW TORNADOES…IS EXPECTED TO STEADILY INCREASE BY LATE MORNING/EARLY AFTERNOON…INCLUDING PIEDMONT PORTIONS OF NC INTO WESTERN/CENTRAL VA AND ADJACENT PARTS OF MD/EASTERN WV/SOUTHERN PA. CURRENT THINKING IS THAT ONE OR MORE WATCHES ARE LIKELY FOR THE MAJORITY OF THE REGION BY LATE MORNING.

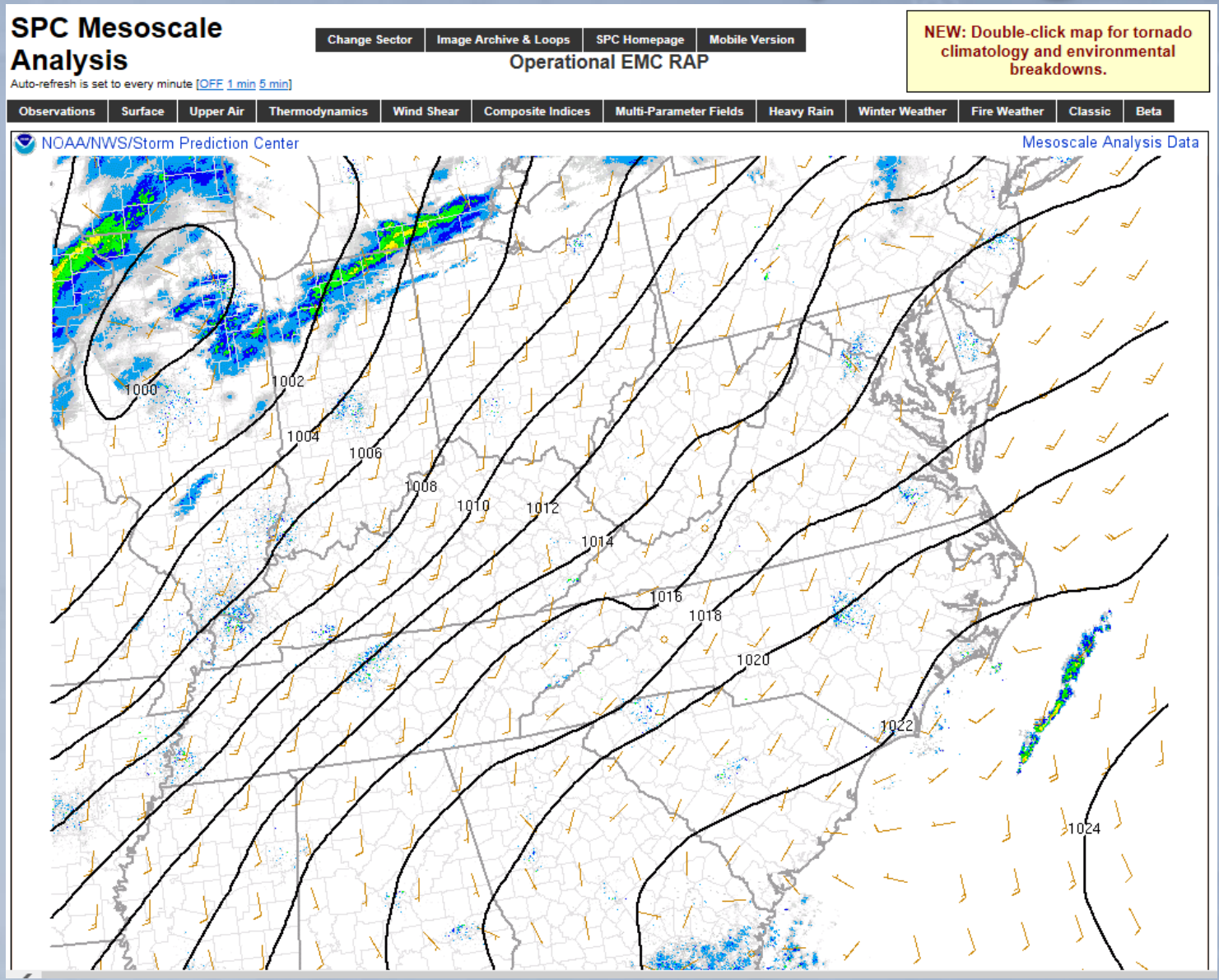
SPC Outlooks



The Day 4-8 Severe Weather Outlook denotes general areas where severe weather may occur.

The addition of the 15% line started in Dec 2014.

SPC Mesoscale Analysis Page



http://www.spc.noaa.gov/exper/mesoanalysis/new/viewsector.php?sector=17

Review Time

- **Tornado or Funnel**
- **Hail** – Pea sized or larger
- **Rotation** within a storm
- **Wind** – 50 MPH or greater (sustained/gust and measured/estimated)
- **Damage** – Any weather related damage to trees or property. Give as many details as possible.
- **Fog** – Any fog resulting in hazardous driving conditions
- **Heavy Rain** – Measured 1” or More
- **Flooding** – Streams, creeks or rivers out of banks of flooding of roads from poor drainage (including coastal flooding)
- **Ice Accumulation** – Any glaze
- **Snow Accumulation** – Every 2”, any accumulation not reflected in the forecast , storm total
- **Tropical** – Flooding as a result of rain and/or storm surge, tornadoes, wind damage

Very Important Information

If your report is severe thunderstorm hail/wind/tornado/funnel cloud or flooding related, please DO NOT send your report via email!

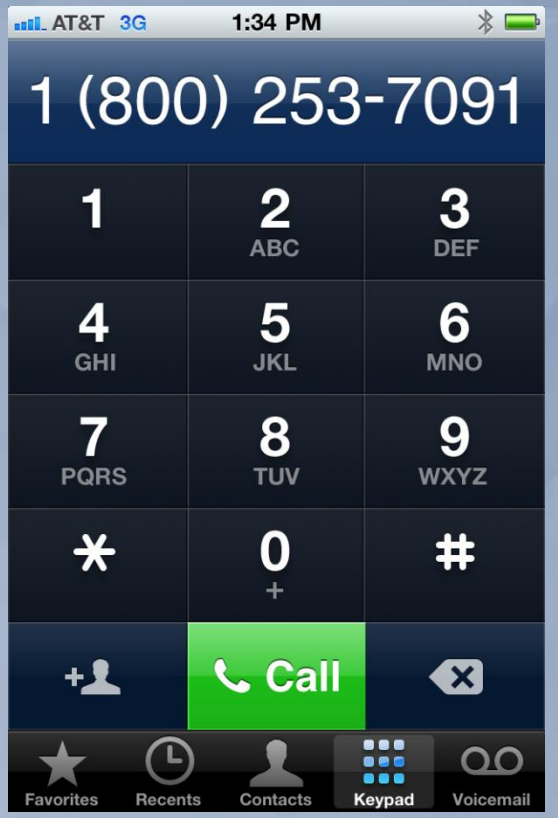
This type of information is time critical and needs to be relayed to forecasters *immediately*.

The best means to get information to the NWS quickly is by the telephone or Amateur Radio

PLEASE DON'T WAIT FOR US TO CALL YOU!

Making a Report

- Include your **full name and Spotter Number**!
- What are you reporting?
- What time was the event?
- Where did the event occur?

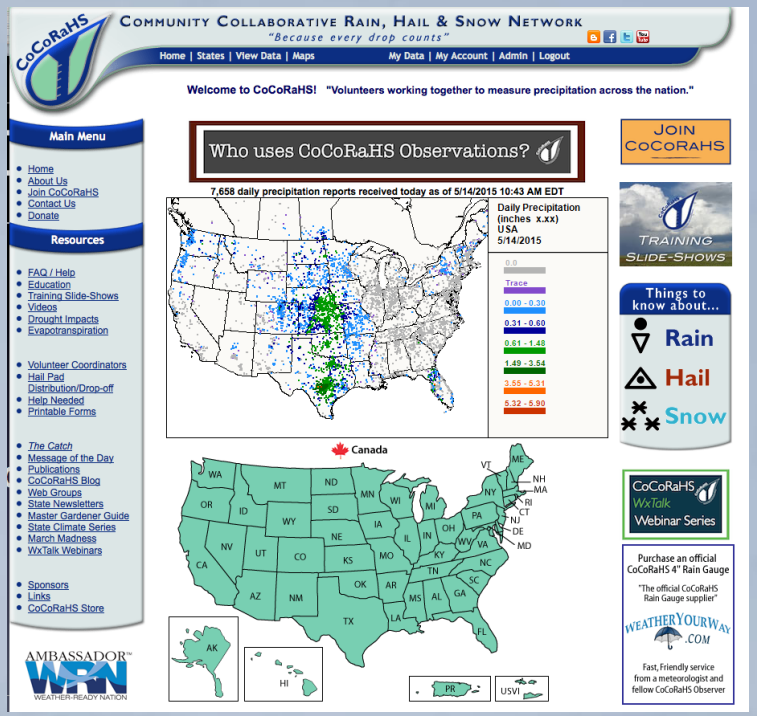


The more specific you are the better!

Email delayed reports, call in the rest!

CoCoRaHS

In addition to being a NWS spotter, you also have to opportunity to participate in this separate volunteer program if you choose…



How can I join the network?

Five easy steps

Simply sign-up on the CoCoRaHS web page: www.cocorahs.org

Obtain a 4” plastic rain gauge

View the on-line “training slide show” or attend a training session

Set-up the gauge in a “good” location in your yard

Start observing precipitation and report on-line daily

Questions or Comments?

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